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THE VALUE OF QUANTITATIVE INTERPRETATION OF GRAVITY DATA*

D. C. SKEELS†

ABSTRACT

Although there is no unique interpretation of a given set of gravity data, there are many cases in which quantitative interpretation is decidedly worthwhile. This is especially true in cases where the gravity data are supplemented by a certain amount of geological data, or where the gravity anomaly is of such a shape that the range of possible solutions can be rather closely limited. Three examples are given of interpretations of actual data.

It is a fundamental weakness of the gravitational method of geophysical prospecting that the data cannot be interpreted uniquely; that is, for any given set of data, there is a variety of subsurface distributions of mass, each of which will satisfy the given data. This unfortunate, but inescapable, limitation has led many to the view that gravity data should be regarded as merely qualitative evidence of structure, and that quantitative interpretation is valueless and even misleading.

While this view may often be justified, and while there have undoubtedly been attempts to derive more from the data than they are capable of yielding, there are some cases, as I shall attempt to illustrate, in which the combination of gravity data with a limited amount of other information enables one to rule out many of the theoretically possible solutions, and to find one or more solutions which, although not unique, are consistent with all of the data and with geological experience, and may be regarded as good working hypotheses. Such an hypothetical solution need not be misleading if it is clearly labeled as such; and it may often prove useful in the extrapolation of incomplete geological data. To those who abhor extrapolation and hypothesis, it should be pointed out that many of

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† Standard Oil Company of New Jersey.

the decisions of the petroleum geologist must be based upon extrapolation from rather meager data. It is true that the use of the seismograph as removed some of the necessity for "guessing," but there are many cases in which seismic data are not available, and in which the geologist must base his decision on gravity data plus a certain amount of geological information. His decision, which may involve expenditures of large sums of money by his company, is usually based upon some hypothesis about subsurface conditions. Quantitative interpretation of the gravity data may indicate whether or not a given hypothesis is consistent with the gravity data; and it may suggest other hypotheses which fit the gravity data better, and the geological data equally well. The choice between hypotheses which are equally favored by the geophysical data should, I believe, rest with the geologist.

The examples given here were taken from the files of the Standard Oil Company of New Jersey, and were chosen to illustrate certain types of information that may be derived by a quantitative study of the gravity data. The anomalies chosen were all of sufficient elongation that they could be treated as two-dimensional without introducing serious error, and this greatly simplified the calculations. For obvious reasons, no geographical location or other identification can be given for the data.

Example I (Fig. 1)

The available geological data are obtained from the wells shown on the left side of the profile. In addition, the base of the bed "C" was determined by seimsograph on the right-hand side. The contacts between "A" and "B" and between "C" and "D" are unconformities. The outside well, at the extreme left of the profile, was dry. One of the wells, that on the extreme right, penetrated the granite basement.

The gravity data show a high to the right of the field. It is obvious that the observed gravity must be due to a mass deeper than the seismograph horizon, and considerably steeper. The few density determinations which are available (from cores) indicate that the only important density contrast is that between the granite and the sediments. From geological considerations, it seems probable that the surface of the granite must be at least as steep as the top of the bed "D," on the left flank. If we draw the granite surface conformable to the top of "D," in the vicinity of the wells, we find that the gravity data will be satisfied with a density contrast of 0.15, and that the gran-

ite on the left flank would have to have the configuration shown by the broken line. Combining this interpretation with the seismic data, we are led to predict that the producing horizon at the top of bed "D" should be encountered on the left flank of the structure in approximately the position indicated.

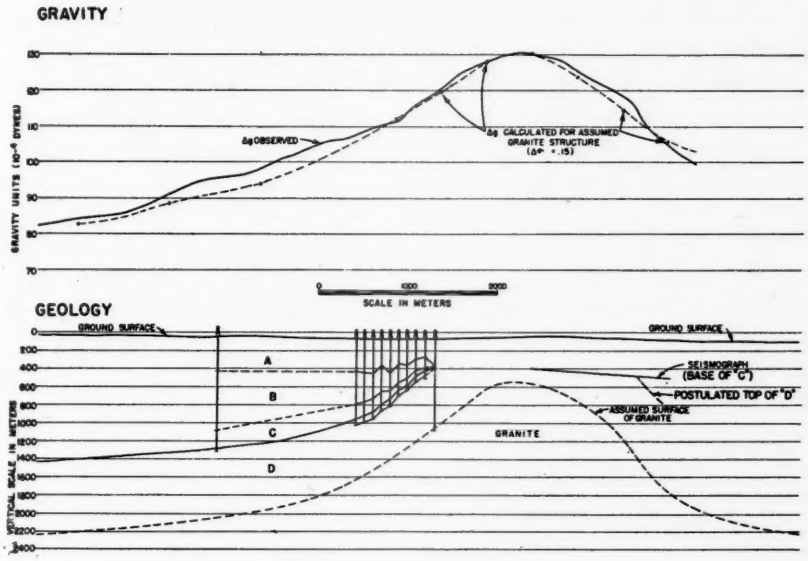


FIG. 1. Use of gravity for extrapolation of geological data.

The assumptions involved in this interpretation are:

1. That the gravity anomaly is all due to the granite-sedimentary contact. A small part of the anomaly may be due to the contact C-D, but this cannot be very important, since, on the evidence of the seismograph, this surface is relatively flat on the right-hand side, whereas the gravity anomaly is steep on both sides. Another possibility is that the anomaly is due to an intrusive mass within the basement, but, if this were true, it would be hard to explain the rather close correlation between gravity and structure on the left side of the profile.

2. The assumption is made that the granite surface has about the same slope as the top of "D." The granite is not likely to be less steep than this horizon; it may however, be steeper, in which case the density contrast would have to be less than 0.15, and the granite

structure larger in amplitude. Against this alternative, we have the fact that our assumed density differential of 0.15 is actually somewhat lower than that indicated by the measured core densities; if we make the granite surface steeper, the discrepancy will be still greater.

It will be noted that although "C" rests on "D," on the left flank, our interpretation demands additional beds between "C" and "D" on the right flank. This is consistent with the paleontological evidence for there is a fairly large time break between "C" and "D."

This example is given to illustrate the possibility of using gravity data to extrapolate incomplete geological data. The interpretation is obviously not the only one possible, but is regarded as a plausible hypothesis, which is consistent with all of the known data.

Example II (Figs. 2 and 3)

Where geological structure is well delineated by seismograph and drilling, gravity data can add little to our knowledge of the structure.

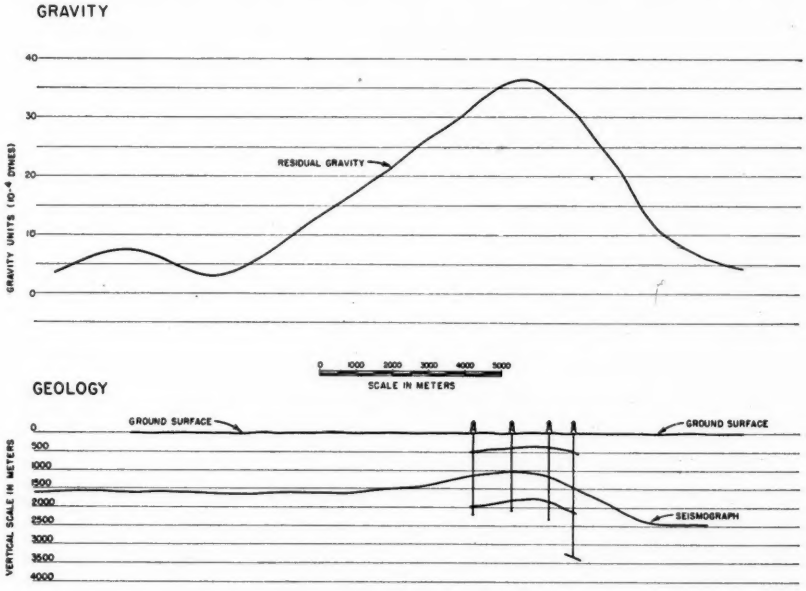


FIG. 2. Geological, gravitational, and seismic data for a producing structure.

A gravity survey over such a known structure may, however, give information about differential densities, which information will be useful in interpreting other gravity anomalies in the same or ad-

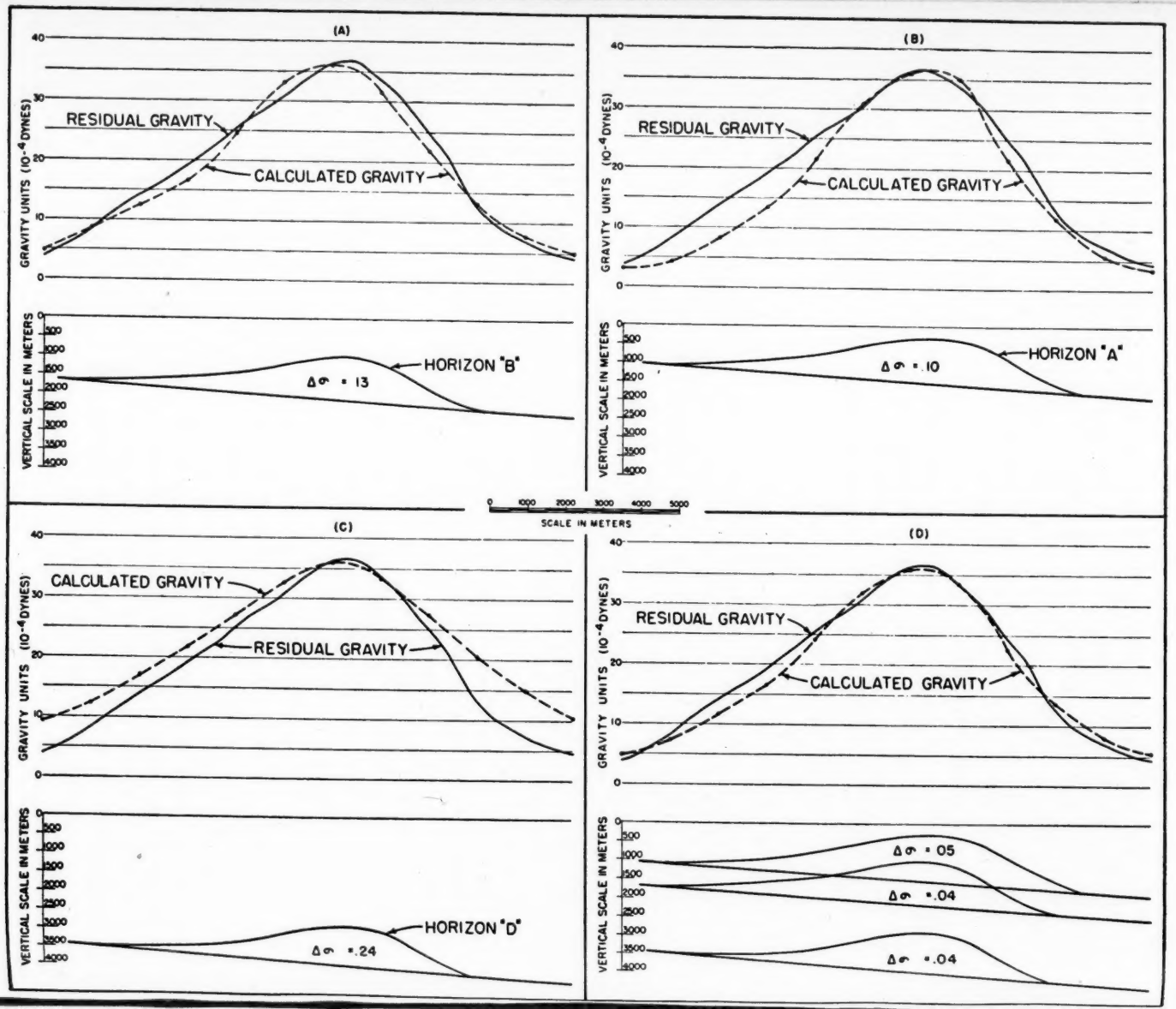
jacent areas. In this example we have the residual gravity anomaly, after removing the regional effect, and the geological structure as revealed by the seismograph and drill (Fig. 2). It will be seen that the gravity anomaly agrees in position with the structure, and there can be little doubt that the anomaly is chiefly due to density contrasts within the sedimentary section, which was only partially penetrated by the deepest well shown.

One difficulty is that we do not know at which horizon the density contrast occurs; and, indeed, a consideration of the lithology suggests that there probably is no single horizon of large contrast, but that more probably the density increases with depth either in a continuous or in a step-like manner. We can, however, calculate what the density contrast would be if it were all located at one horizon, and if we do this for different horizons, the total density differential will probably lie somewhere between the extreme values. In Fig. 3-A the contrast is assumed to be at "B," the seismic horizon. The effect of the excess mass between this horizon and the sloping base line was calculated, and is shown as a broken line; the observed profile (residual gravity) is shown by the solid line. The base line was made to slope, because the seismograph indicates regional dip, and the effect of this regional was eliminated from the residual gravity profile.

Figs. 3-B and 3-C show the calculated effects when the density contrast is taken to be at horizons "A" and "D," respectively. For each horizon, that density was found which would make the maximum value of the calculated anomaly agree with that of the observed anomaly. Horizons "D" and "A" were extrapolated so as to be conformable to "B," which is known by seismograph.

Finally, in Fig. 3-D the combined effect of all three horizons, with the density contrasts .05, .04, and .04 at horizons "A," "B," and "D" is shown.

It is obviously impossible to determine from the gravity data how the densities are distributed. The assumption that all of the density contrast is located at the deep horizon "D" (Fig. 3-C), can probably be ruled out, for even if we make the structure considerably sharper on this horizon, the calculated anomaly will be too wide to match the observed profile. Fig. 3-D gives the best fit of all; but we could have obtained an even better fit in 3-B if we had changed the shape of the bed "A" slightly. No matter how the densities are distributed, however, the total density contrast cannot be more than about 0.15, if the gravity and seismic data are both right. This is a

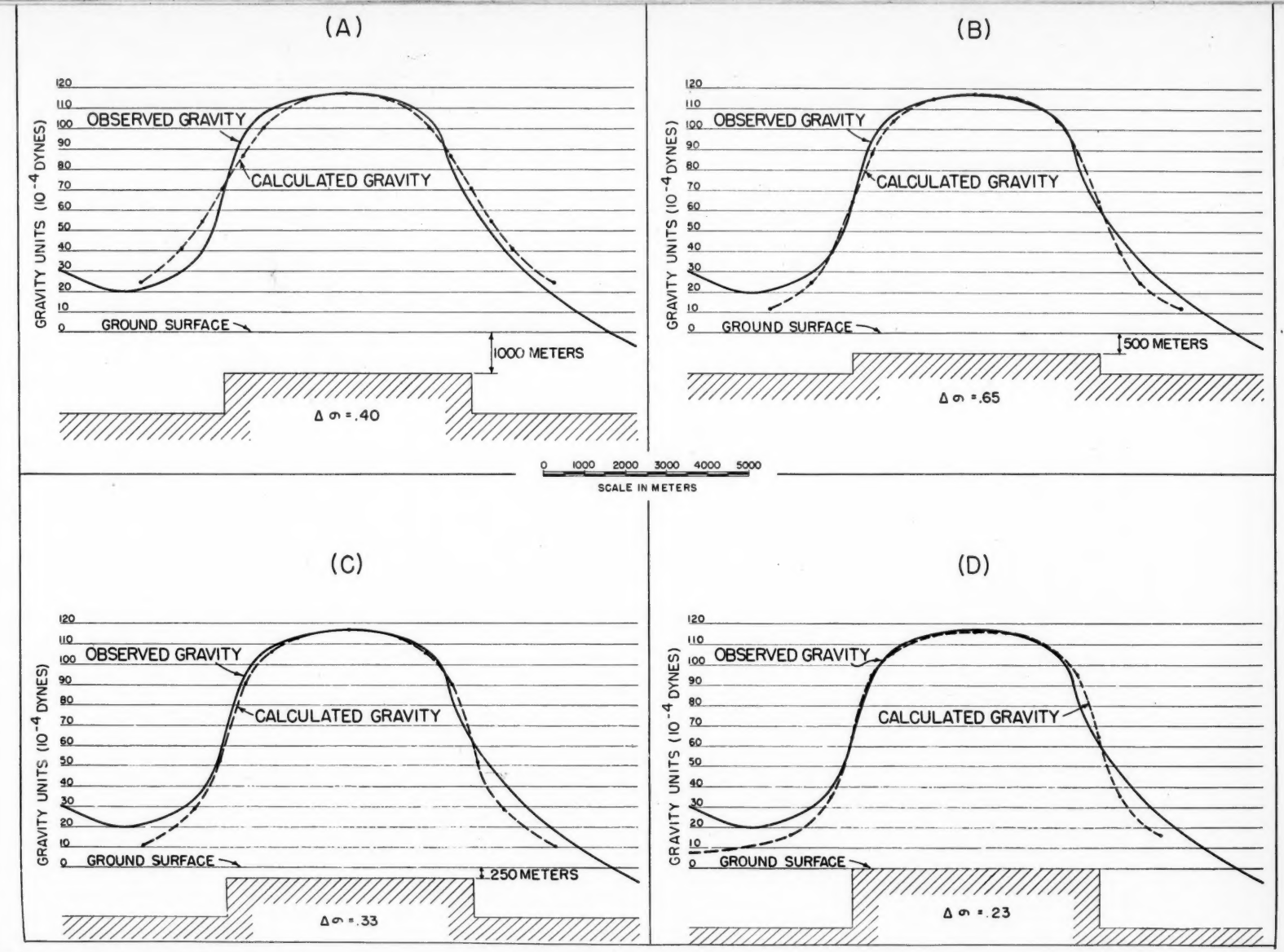

(A)
RESIDUAL GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10⁻⁴ DYNES)
VERTICAL SCALE IN METERS
HORIZON "B"
Δσ = 13
(B)
RESIDUAL GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10⁻⁴ DYNES)
VERTICAL SCALE IN METERS
HORIZON "A"
Δσ = .10
SCALE IN METERS
(C)
CALCULATED GRAVITY
RESIDUAL GRAVITY
GRAVITY UNITS (10⁻⁴ DYNES)
VERTICAL SCALE IN METERS
HORIZON "D"
Δσ = .24
(D)
RESIDUAL GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10⁻⁴ DYNES)
VERTICAL SCALE IN METERS
Δσ = .05
Δσ = .04
Δσ = .04

rather low figure, considering the normal increase of density with depth in sedimentary beds. A possibility that we have not considered is that there is a reversal of density contrast at some horizon, with an increase at another horizon. For example, if the material above horizon "A" were denser than that between "A" and "B" by, say 0.10, then we might have a density contrast of about 0.25 on "B"; but in this case the total density differential would still be about 0.15, the upper differential being regarded as negative.

Example III (Fig. 4)

In the previous example the depth of the disturbing mass could be limited to some extent, although we still had a rather wide range of possible depths. It sometimes happens that the shape of the anomaly is such as to limit the depth rather closely. Fig. 4 shows a gravity anomaly which, from its shape, must be due to a steep-sided structure of considerable width, either an intrusion or a horst. The latter seems more probable from a consideration of the regional geological setting. No geological data are available in the immediate area of the anomaly, but the geologic section exposed in adjacent areas consists of a thick limestone series overlain by shales, and it is assumed that the only important density contrast is at the surface of the limestone. If this assumption be correct, we can use the gravity data to get some idea of the depth of the limestone on the axis of the anomaly. Fig. 4 shows four assumed structures, and the calculated gravity effect of each, compared with the observed effect. Fig. 4-A gives a very poor fit, 4-B fits somewhat better; Figs. 4-C and 4-D are much better than either of the other two. From these figures we can conclude, I believe, that the limestone can hardly be deeper than 500 meters on the axis of the anomaly, and is probably considerably shallower than this figure.

The validity of this estimate depends, of course, upon the validity of the data, and of our assumption that the limestone surface is the only important density contrast. As far as the data are concerned, it should be stated that this is only one of several profiles across the anomaly, all of which show about the same character, so the sharp "corners" which reveal the shallow nature of the disturbing mass can hardly be accidental. As for the assumption that the limestone is the only important density contrast, we would feel much better if we had actual data on the specific gravities of the rocks exposed in adjacent areas. It is just possible that there is a density contrast


(A)
OBSERVED GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10^{-4} DYNES)
GROUND SURFACE
1000 METERS
$\Delta\sigma$ = .40
(B)
OBSERVED GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10^{-4} DYNES)
GROUND SURFACE
500 METERS
$\Delta\sigma$ = .65
0 1000 2000 3000 4000 5000
SCALE IN METERS
(C)
OBSERVED GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10^{-4} DYNES)
GROUND SURFACE
250 METERS
$\Delta\sigma$ = .33
(D)
OBSERVED GRAVITY
CALCULATED GRAVITY
GRAVITY UNITS (10^{-4} DYNES)
GROUND SURFACE
$\Delta\sigma$ = .23

somewhere within the shale section without any corresponding change in visible lithology.

The examples that have been cited are all somewhat exceptional, in that the anomalies are greatly elongated in one direction, and could be treated as two-dimensional. Where this condition is not fulfilled, the calculations of the gravitational effects of assumed structures are rather tedious, although still quite possible. Whether or not the results will justify the time spent will depend, of course, on the problem, and on the amount of other data available.

I am indebted to the officials of the Standard Oil Company of New Jersey for permission to publish this paper.

A MECHANICAL INTEGRATOR FOR THE COMPUTATION OF GRAVITY ANOMALIES*

ARNOLD J. F. SIEGERT†

ABSTRACT

With the instrument here described the gravity anomaly caused by an arbitrarily given finite body can be computed. The integrator is operated by tracing the contour lines representing the body in a manner similar to the operation of a planimeter. The instrument is useful mainly in the indirect method of interpretation of observed gravity anomalies, in the computation of terrain corrections, and in the evaluation of magnetic anomalies. Its design is based on a formula which expresses the gravity anomaly caused by an infinitely thin slab, bounded by a closed curve, as a line integral over this curve.

The gravity integrator described here was designed mainly as an aid in the indirect interpretation of gravity anomalies. In this method a geologic body is assumed, the gravity anomaly caused by it is computed and compared with the observed anomaly. If there is no agreement between computed and observed anomaly, the shape, depth, and density of the hypothetical body have to be changed. If there is reasonable agreement, the assumed body can be the cause of the gravity anomaly. The main disadvantage of this method lies in the excessive amount of computation work it requires. Even if the shape of the hypothetical body is oversimplified, so that its gravity anomaly can be expressed in terms of simple functions, the amount of work involved in the numerical evaluation of the theoretical gravity anomaly is still prohibitive in most cases.

The mechanical integrator here described eliminates both the mathematical and the numerical work, and replaces them by an operation as simple as the operation of a planimeter.[1] The instrument is shown in the photograph of Fig. 1, and, schematically, in Fig. 2. It comprises a main arm PS to which a stylus and a perpendicular extension arm ST are attached rigidly in the point S. The depth is set on the extension arm; the length of ST represents the depth. An auxiliary arm PT is pivoted to the extension arm in T. Both main

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† Stanolind Oil and Gas Company, Tulsa, Oklahoma.

[1] An integrator for the two-dimensional problem was constructed by G. A. Gamburzeff, Gerl. Beitr. *24*, 83, 1929. An instrument for the evaluation of certain integrals occurring in gravity interpretation has been described by F. Kaselitz, Zeit. Geophys. *8* (3/4), 191, 1932. The latter can be used for the three-dimensional problem but requires plotting of intermediate results and an additional integration. (See also *Geophysical Exploration*, C. A. Heiland, pp. 157, 269.)

arm and auxiliary arm slide and turn in the pivot point P. The wheel arm PW is perpendicular to PS and of constant length. The plane of the wheel W is made to form an angle $\alpha = \angle SPT$ with PW and, therefore, an angle $90° - \alpha$ with PS. In the actual construction it turned out to be advantageous to attach the wheel not to the wheel arm it-

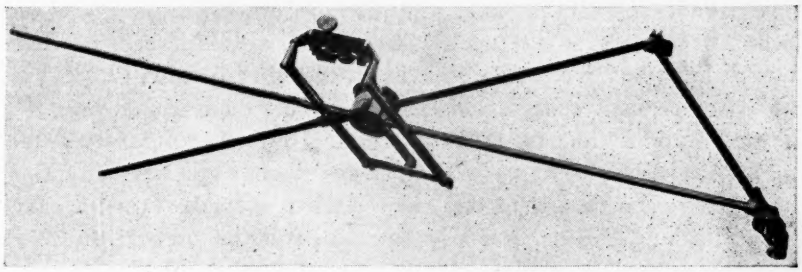


FIG. 1. Photograph of the integrator.

self but to a pantograph arrangement, which holds the wheel at the correct place and under the angle required.

To find the gravity anomaly of a given body a contour map of this body is drawn on a convenient scale. The pivot point of the instrument is set on the point of observation, that is, the point for

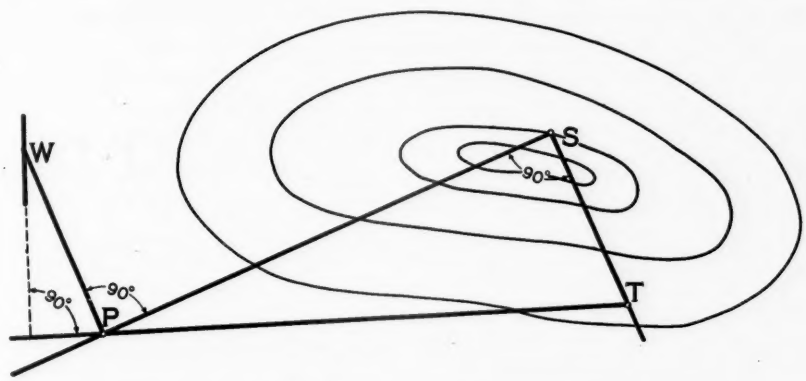


FIG. 2. Schematic diagram of the integrator.

which the gravity anomaly is to be computed. It is held in place by a needle protruding from the bottom of the pivot. The stylus S is placed on an arbitrary point of the innermost contour line. The wheel

W is turned to make the wheel scale read zero, or its reading is noted and later subtracted from the result. The depth represented by the contour line is set on the depth scale ST. The depth scale and lateral scale must be the same; if, for instance, one inch on the map represents 4000 ft., the depth scale has to be set to one inch for the 4000 ft. contour, to $\frac{1}{2}$ inch for the 2000 ft. contour, etc. The stylus S is then led once around the contour line. The direction in which the stylus has to be led depends on whether the wheel scale shows increasing readings if the stylus is led around P in clockwise or in counterclockwise direction. It shall be assumed that the wheel reading increases if S is led around P in clockwise direction. To find the gravity value, all contour lines have to be traced in counterclockwise direction. It is easily seen that then the wheel reading increases when a curve not containing P is encircled, and decreases if the curve contains P. After the innermost contour line has been traced the stylus is moved to the starting point on the next contour line and the depth of this contour line is set on the depth scale. While the starting point on the first contour line is arbitrary all other starting points have to lie on a straight line through P and the first starting point and the stylus has to be moved on this straight line while changing contour lines, in order not to disturb the wheel reading. Care must also be taken not to move the stylus while changing the depth setting, so that the wheel will not turn in this procedure. After setting the depth scale, the contour line is traced, the stylus moved to the next contour line, and the procedure is repeated for all contour lines of the hypothetical body. After all contour lines have thus been traced, the wheel scale is read. If none of the contour lines encircled the point P, the reading I of the wheel is multiplied by $\gamma\rho t/c$ to obtain the value of the gravity anomaly at P. ρ is the density excess of the body over its surroundings; t is the contour interval; c is the calibration constant of the instrument and γ is Newton's constant. The numerical value of γ, if the result is desired in gravity units (1/10 milligal) is:

66.6	if t is in km
107.2	if t is in miles
0.0203	if t is in feet
2.03	if t is in 100 feet

The above formula has to be changed slightly if some of the contour lines encircle the point P. If n is the number of these contour

lines, the value $2\pi nc$ has to be added to the wheel reading before multiplication with the above constant. The formula becomes:

$$g = \frac{\gamma\rho t}{c}(I + 2\pi nc).$$

The calibration constant of the instrument can be calculated, but it is simpler to find it empirically. To calibrate the instrument the stylus is led on a circle of radius r around the point P, with the depth setting at z, in clock wise direction. The wheel reading I is then given by

$$I = 2\pi c \sin\alpha, \quad \text{in which} \quad \sin\alpha = [1 + (r/z)^2]^{-1/2}.$$

To obtain an accurate value of c, several combinations of r and z are chosen and the values of I read on the instrument. The sum of the corresponding values of $2\pi c \sin\alpha$ is divided into the sum of the instrument readings to obtain c. In Table I a number of instrument

TABLE I. EXAMPLE OF MEASUREMENT OF CALIBRATION CONSTANT

r/z	$2\pi \sin\alpha$	$2\pi c \sin\alpha$	I (*measured*)
½	5.620	667.0	(4, 8) 667.0
1	4.443	527.4	(5, 5) 527.3 (7, 7) 527.6
2	2.810	333.5	(6, 3) 334.1 (10, 5) 333.3 (14, 7) 333.4
4	1.5237	180.9	(12, 3) 179.4

$c = 118.7$. (12, 3) means: measured with $r = 12$, $z = 3$.

c is obtained by dividing the sum of all measured values I by the weighted sum of the values $2\pi \sin\alpha$: $5.620 + 2\times 4.443 + 3\times 2.810 + 1.5237$. The largest discrepancy between the computed values $2\pi c \sin\alpha$ and the measured values of I is 1.5 divisions of the wheel scale (1 revolution = 100 divisions). For a body of density excess one and a contour interval of 1000 feet, this error would amount to only ¼ gravity unit (0.025 milligal).

readings are shown together with the values of $2\pi \sin\alpha$ and the values of $2\pi c \sin\alpha$, computed with the value of c thus calculated. Circles for which the value of r/z is the same must give the same wheel reading. Comparison of the instrument readings and the values of $2\pi c \sin\alpha$ shows the instrument to be accurate within 0.25 gravity unit for $\rho = 1$ and $t = 1000$ ft.

In using the instrument it will, in general, be possible to place the point of observation so that the foot of the pivot does not cover any piece of a contour line. It is, for this purpose, advantageous to

choose the scale of the map as large as possible. This will also diminish the error in tracing. If it is not possible to avoid such points of observation, the contour line should be traced as closely as possible to the pivot, and the stylus then led around the pivot on an arc until it meets the contour line again as shown in Fig. 3. This amounts to neglecting the cross-hatched part of the slab represented by the contour line. To correct for this omission the cross-hatched part only is drawn on a larger scale and traced on this scale. The

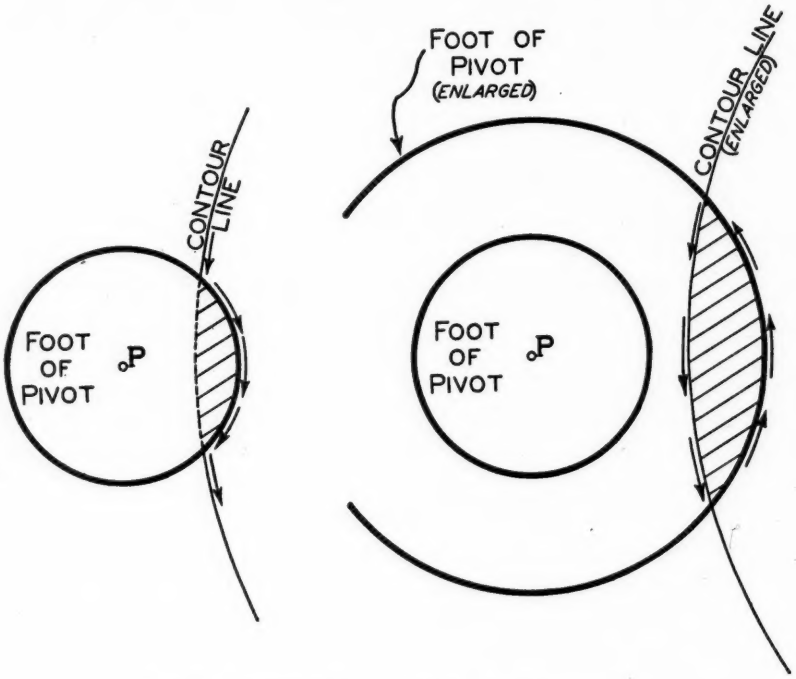


FIG. 3. Illustrating the procedure when a contour line passes under the foot of the pivot.

depth setting has to be changed, of course, to correspond to the larger scale. The resulting instrument reading is added to the former one which is thus corrected for the omission of the cross-hatched part. Since the part of the contour line covered by the pivot can, in most cases, be considered a straight line, a correction table can be prepared beforehand by means of the instrument. A scale of angles can be provided for on the foot of the pivot and the corrections are then read from the table which lists the instrument readings for various angles

between the entrance and the exit of the contour line and for various depths. If P lies exactly on a contour line and the covered part of the contour line may be considered straight, the instruments reads $c\pi[1+(r_0/z)^2]^{-1/2}$ instead of $c\pi$, and the correction is, therefore, $c\pi(1-[1+(r_0/z)^2]^{-1/2})$, where r_0 is the radius of the foot of the pivot.

The case of bodies whose density excess varies with depth can be treated easily by a slight change of procedure. Rather than reading the instrument only after all contour lines are traced, it is read after each contour line separately or after each group of contour lines representing slabs with the same density excess over their surroundings. The instrument readings are then individually multiplied by $\gamma\rho_i t/c$, where ρ_i is the density excess of the individual slab, or of the group of slabs in question. This procedure will be of value, for instance, for the calculation of the gravity anomaly caused by salt domes piercing sediments of different densities.

The application of the instrument to the computation of terrain corrections will decrease the time necessary for the computation from one hour per station to probably less than ten minutes, in cases where the terrain irregularities cannot be approximated by simple shapes like infinitely long inclined steps or ridges. If terrain corrections are to be computed, the instrument is operated on a topographic map which does not need to be very accurate. If the contour interval chosen is t, the contour lines are drawn at elevations $t/2$, $3t/2$, $5t/2$, etc., above and below the station elevation. These elevation values, regardless of sign, are used as z values. Contributions of contour lines above and below the station are to be added to the gravity value if elevation and Bouguer correction have been applied beforehand.

In a similar manner, the instrument can also be used for the computation of the isostatic correction.

The integrator is also useful for the computation of the vertical component of the magnetic anomaly caused by an arbitrarily given finite body, provided the magnetization can be considered homogeneous, and caused by a known magnetic field, for instance, the magnetic field of the earth. The use of the instrument in this case is based on the Eötvös formulas which express the magnetic field in terms of the derivatives of the gravitational field: the vertical component H_z of the anomaly, which usually is the only one measured, is given by

$$H_z = \frac{\kappa H_x^{(0)}}{\gamma\rho}\frac{\partial g}{\partial x} - \frac{\kappa H_z^{(0)}}{\gamma\rho}\frac{\partial g}{\partial z}.$$

H_z is counted positive if it increases the normal earth magnetic field, $H_z^{(0)}$ and $H_x^{(0)}$ are the vertical and horizontal components of the normal earth field, counted positive, and κ is the susceptibility of the body. The x axis is horizontal and directed towards the nearest magnetic pole with x increasing in the direction of the pole. The z axis is vertical and z increases downward. ρ is arbitrary because it appears as a factor in g and cancels out.

The contribution of $H_x^{(0)}$ can be obtained easily by graphical differentiation of the gravity map computed by means of the integrator. The increase of the gravity per unit distance in the direction of the magnetic pole is determined from the map and multiplied by $\kappa H_x^{(0)}/\gamma\rho$. It is advantageous to begin this procedure in places on the map where this increase is largest, positive or negative, since this contribution is often so small that it may be neglected in all other places.

The determination of the contribution of the vertical component of the earth field is based on replacing the differential quotient $\partial g/\partial z$ by a difference quotient. The value of g is computed twice, with each value of z replaced by $z+\frac{1}{2}\Delta z$ and by $z-\frac{1}{2}\Delta z$. The difference between these values for g is divided by Δz, to obtain an approximation for $\partial g/\partial z$. The value of Δz has to be chosen large enough to obtain the difference in the gravity values with sufficient accuracy but small enough to approximate the differential quotient well. A value equal to the contour interval t should give satisfactory results. A less accurate value is obtained using z and $z+\Delta z$, instead of $z+\frac{1}{2}\Delta z$ and $z-\frac{1}{2}\Delta z$, but even then the accuracy will probably still be sufficient for magnetic work.

The question often arises whether an observed magnetic anomaly is caused by the same body which causes a gravity anomaly coinciding with it or in its immediate neighborhood. Under the assumption of homogeneous density and homogeneous magnetization, the magnetic anomaly may be determined directly from the observed gravity anomaly, without any assumptions concerning the shape of the body. The determination of the contribution of the horizontal component of magnetization obviously requires only a differentiation of the gravity anomaly. The contribution due to the vertical component of magnetization can be computed by means of the instrument. This procedure is based on the theorem that the gravity anomaly at any point above the earth surface (assumed to be a plane) is equal to the gravity anomaly caused by the "ideal perturbing layer," that is, an infinitely thin distribution of surface density proportional at any

point to the gravity value measured at this point. The gravity values, which would have been measured at an altitude Δz above the surface of the earth, are thus computed by tracing all lines of equal gravity with the stylus of the instrument, keeping the depth setting constant at Δz. The instrument reading, corrected in the usual way for contour lines encircling the point P, is multiplied by $\Delta g/2\pi\gamma$ according to the Bouguer formula, where Δg is the contour interval of the gravity map. Knowing thus the gravity values at the surface and at an altitude Δz, the magnetic anomaly at an altitude $\frac{1}{2}\Delta z$ is determined. If Δz was chosen small enough, this amounts to a knowledge of the magnetic anomaly at the surface of the earth. The magnetic anomaly thus obtained theoretically is then compared with the measured anomaly in order to decide whether the same body caused both anomalies. The procedure here described may sometimes be useful for gravity interpretation, too, since some authors believe that the vertical gradient of gravity is, in certain cases, more diagnostic than the gravity values themselves.[2]

In the same way, the gravity values at an altitude of the order of one mile can be computed. By subtracting the computed values from the measured values the influence of deep-seated structures is greatly reduced. This procedure may be used instead of subtracting regional gradients to obtain a map on which the effect of shallow localized structures stands out better. This method is, of course, of qualitative value only, but may serve its purpose better than the subtraction of rather arbitrarily chosen regional gravity features, in cases where the regional gradient is not outstanding and simple.

ANALYTIC BASIS OF THE DESIGN OF THE INTEGRATOR

The fundamental operation of the instrument is the computation of the gravity anomaly of an infinitely thin plane horizontal layer bounded by an arbitrarily given curve. The value thus obtained approximates the gravity anomaly due to a slab of finite thickness bounded by the same curve, within the limits of accuracy desired for gravity interpretation. Any given finite body can be composed of such slabs, with any accuracy desired. The contour lines of the body are the peripheries of these slabs. The accuracy obtained is very good as long as the thickness of the individual slabs is smaller than the shortest distance from the point of observation to the body. In case of

[2] Evjen, H. M. The Place of the Vertical Gradient in Gravitational Interpretations. GEOPHYSICS, Vol. I, No. 1, pp. 127–136 (Jan., 1936).

doubt, the computation may be repeated with a narrower contour interval. For bodies with large vertical extension and steep flanks, another design for the instrument will be described later.

The instrument was designed on the basis of a formula which expresses the gravity of an infinitely thin slab bounded by the curve C as a line integral over this boundary:

$$g = -\gamma\rho t \oint \frac{z}{\sqrt{r^2+z^2}}\, d\phi \text{ for } P \text{ outside of } C,$$

and

$$g = -\gamma\rho t \left[\oint \frac{z}{\sqrt{r^2+z^2}}\, d\phi - 2\pi \right] \text{ for } P \text{ inside of C.}$$

z is the depth the slab, $r=r(\phi)$ is the equation of the curve C in polar coordinates around the point P. The instrument performs the integra-

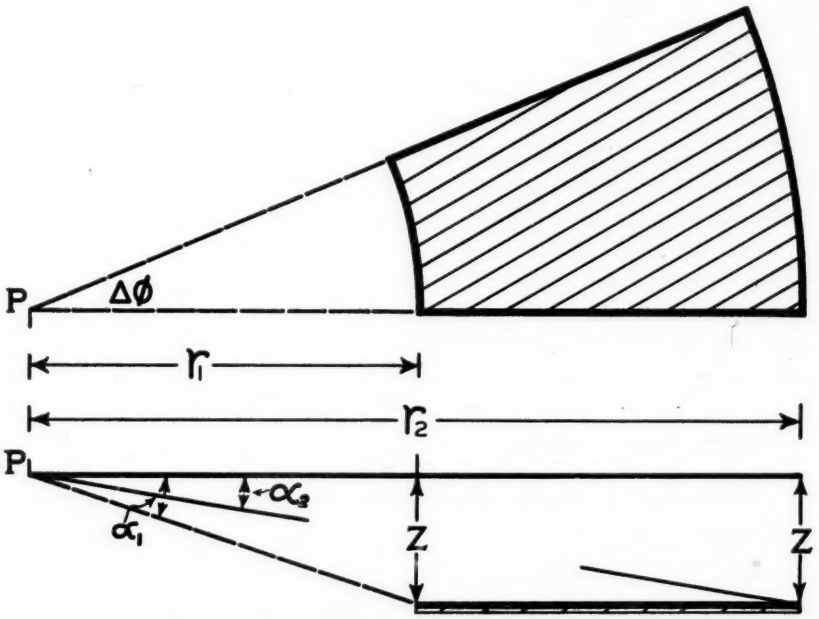


FIG. 4. Top and side view of special form of element used to derive the contour integral which forms the analytic basis of the design of the integrator.

tion if the curve C is traced with the stylus. A simple derivation of the principle of the instrument is based on the formula of an infinitely thin element of the shape shown in Fig. 4 in top view and side view. The element is part of a plane at depth z below the surface of the

earth. It is bounded by two concentric circles and two straight lines intersecting in the common center of the circles. The gravity anomaly g due to this element at a point on the earth surface vertically above the center of the circles is given by

$$g = \gamma\rho t\Delta\phi\left[\frac{z}{\sqrt{z^2 + r_1^2}} - \frac{z}{\sqrt{z^2 + r_2^2}}\right]$$

where γ is Newton's constant, ρ the density excess of the body over its surroundings, r_1 and r_2 are the radii of the circles and $\Delta\phi$ is the angle between the two straight lines. If α_1 and α_2 are the angles shown in the vertical section in the lower part of Fig. 4, this formula can also be written

$$g = \gamma\rho t\Delta\phi(\sin\alpha_1 - \sin\alpha_2).$$

This formula is the limiting case for small thickness of formula 7–41c, p. 149, in *Geophysical Exploration* by C. A. Heiland.

If the stylus S of the instrument moves on a straight line through P the wheel does not move. If it is led on a circle of radius r around P through an angle $\Delta\phi$ the center of the wheel moves on a circle of radius PW through the same angle. The wheel partly slides, partly rolls. The rolling part of the motion which is read on the wheel scale will amount to $c\sin\alpha\Delta\phi$. The constant c is determined by the length of the wheel arm PW, the radius of the wheel and the scale. If the stylus is led in a counterclockwise direction around the element, shown in Fig. 4, the wheel scale will read $I = c\Delta\phi\ (\sin\alpha_1 - \sin\alpha_2)$. Comparing this value with the formula for the gravity g of this element, it is seen that

$$g = \frac{\gamma\rho t}{c} I.$$

This relation between wheel reading and gravity will now be shown to be true in the general case of an infinitely thin layer bounded by an arbitrarily given curve C if P lies outside of C. The case of P in C will be treated later. In Fig. 5 the area in C is shown roughly approximated by elements of the shape considered before. To find the gravity at the point P, the outlines of these elements can be traced as shown by the arrows, the resulting instrument readings added and the above formula applied. It is seen, however, that the lines in the interior would be traced twice in opposite directions, and therefore may be omitted. Only the outside boundary need be traced. By increasing the number of elements the outline can be made to approxi-

mate the curve C more and more closely. The contributions of the dividing lines inside C always cancel, and to obtain the gravity due to the area bounded by C, therefore, the curve C has to be traced, and the equation $g=I\gamma\rho t/c$ holds for the arbitrary curve C, since it holds for the simple element for which it was proven initially.

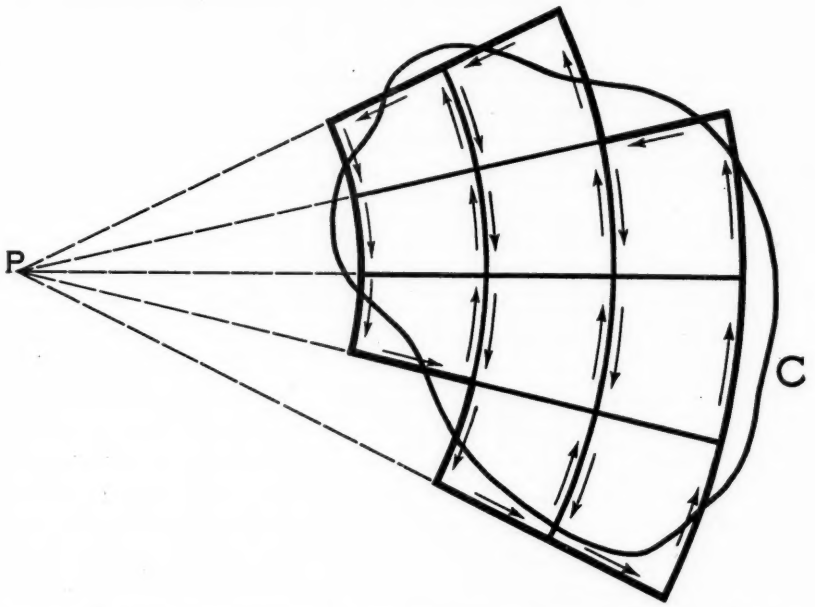


FIG. 5. Illustrating the argument used to extend the contour integral to the case of a thin element with an arbitrary boundary.

If P lies inside C, the curve C is approximated by a curve C', as shown in Fig. 6. C' is identical with C, except for the piece AA', which is replaced by a straight line leading into C, a circle around P and a straight line leading out of C, which is parallel to the first one. In the limit when the two straight lines are made to approach each other and the circle is contracted to zero radius, the area bounded by C', causes the same gravity anomaly as C, but C' does not encircle P. The gravity anomaly due to the area bounded by C may therefore be obtained by tracing C' and applying the above formula. The two straight lines will not contribute to the instrument reading, because they are traced in opposite direction. The infinitesimal circle around P contributes the amount $2\pi c$. Instead of tracing C', therefore, the original curve C may be traced and the value $2\pi c$ added to the instru-

ment reading. The value of the gravity anomaly due to an area bounded by C, therefore, is equal to

$$g = \frac{\gamma\rho t}{c}(I - 2\pi c) \text{ if } P \text{ lies inside } C.$$

If n of the contour lines representing the body encircle the point P, g is given by

$$g = \frac{\gamma\rho t}{c}(I - 2\pi nc)$$

where I is the instrument reading after all of the contour lines have been traced.

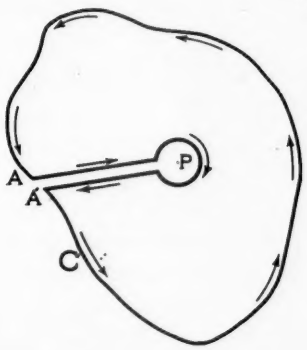


FIG. 6. Contour used in the integration when the point of observation lies within one of the contour lines.

For bodies with large vertical extent and steep flanks, the present instrument would necessitate the tracing of a large number of contour lines of nearly the same shape. A similar instrument has, therefore, been designed for those cases.

The gravity value for a vertical cylinder, extending from a depth z_1 to a depth z_2 and bounded by the curve C, is obtained by integration of the above formulas for the infinitely thin cylinder:

$$g = -\int_{z_1}^{z_2} \gamma\rho dz \oint \frac{z}{\sqrt{r^2 + z^2}} d\phi = \gamma\rho \oint \{\sqrt{r^2 + z_1^2} - \sqrt{r^2 + z_2^2}\} d\phi$$

if P is outside C, and

$$g = \gamma\rho\left\{\oint (\sqrt{r^2 + z_1^2} - \sqrt{r^2 + z_2^2}) d\phi + 2\pi(z_2 - z_1)\right\}$$

if P is inside C.

To compute the integral $\oint \sqrt{r^2+z^2}d\phi$ the wheel, instead of being attached to a wheel arm PW is placed at the point T. The wheel plane is kept perpendicular to PT. The instrument is otherwise constructed as shown in Fig. 1 and 2. If the stylus moves from the point r, ϕ to the point $r+dr, \phi+d\phi$, the wheel rolls by the amount dw:

$$dw = \sqrt{r^2 + z^2}\,(d\phi - d\alpha).$$

If the stylus is made to trace a closed curve C, the wheel rolls the amount w, where

$$w = \oint \sqrt{r^2 + z^2}\,d\phi - \oint \sqrt{r^2 + z^2}\,d\alpha.$$

Since $\sqrt{r^2+z^2}d\alpha$ is independent of ϕ, the second integral vanishes on a closed curve, and, therefore,

$$w = \oint \sqrt{r^2 + z^2}\,d\phi.$$

The procedure to be followed in determining the gravity anomaly is easily derived from the above equations which express g in terms of this integral.

I should like to express my gratitude to Dr. Alexander Wolf for his advice in the design of the integrator and for his encouraging discussions, and to Mr. L. Evans and Mr. P. Guenther for the expert design and construction work. The instrument was designed and built while I was employed by The Texas Company, Houston, Texas. I should like to thank the authorities of this company for their consent to the publication of this paper.

LOCAL AREAL DISTRIBUTION OF VELOCITIES IN THE TEXAS GULF COAST*

B. G. SWAN†

ABSTRACT

This paper presents velocity data obtained from long reversed profile surface shooting on three Texas Gulf Coast projects. Velocity determinations were distributed areally in sufficient detail to permit construction of "Isotime" contour maps representing velocities to a time datum. Maps are presented showing the resulting corrected seismic structure. Also presented are Time-Depth curves of two profiles with curves of nearby well velocity surveys. Two comparisons are made of velocities at common points determined by the long velocity profiles and by Time-Δt analysis of shorter spreads.

Data presented show that velocities determined in the manner described are quite variable over local areas, but can be contoured into fairly regular patterns, and that if applied to the ordinary seismic data profound changes in structural interpretation are effected; that major discontinuities in velocity stratification may be detected; that in the two examples described, velocities obtained from 5400 foot reversed reflection profiles are higher than those obtained by Time-Δt analysis of 1800 foot reversed profiles; and that velocity anomalies determined from surface profile shooting may be associated with faulting in the subsurface beds.

For several years past Continental Oil Company has been securing quite a large amount of velocity information from subsurface shooting in the regular course of seismic operations, both from long reversed reflection profiles and from the shorter spread Time-Δt analysis. It is thought that some of this material may be of interest to the profession.

In this paper are presented chiefly data secured from reversed spreads of about 5400 feet, although some 4500 foot spreads are included. These spreads were of both the reversed basement and reversed surface types. Although several different techniques were used in assembling and computing data from the profiles, the basic principle in each case reverts to the general equation:

$$V^2 = \frac{X_2^2 - X_1^2}{T_2^2 - T_1^2}$$

where

X_1 = distance to near end of spread
X_2 = distance to far end of spread
T_1 = time to nearest detector
T_2 = time to farthest detector

* Presented at the 1942 Spring meeting, Denver, Colorado.
† Continental Oil Company, Ponca City, Oklahoma.

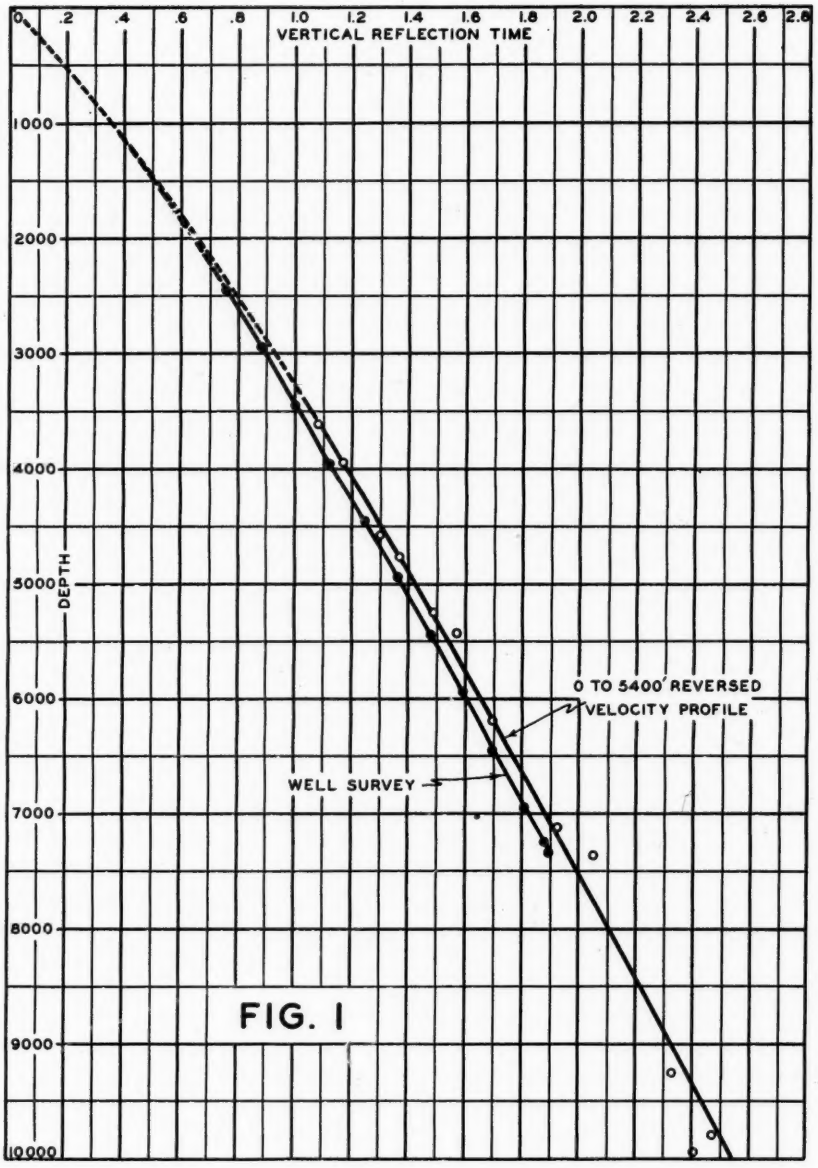


FIG. 1. Typical Time-Depth curve as determined by a 0–5400 foot reversed basement velocity profile (open circles), and Time-Depth curve from a well velocity survey in an adjacent area, (solid circles).

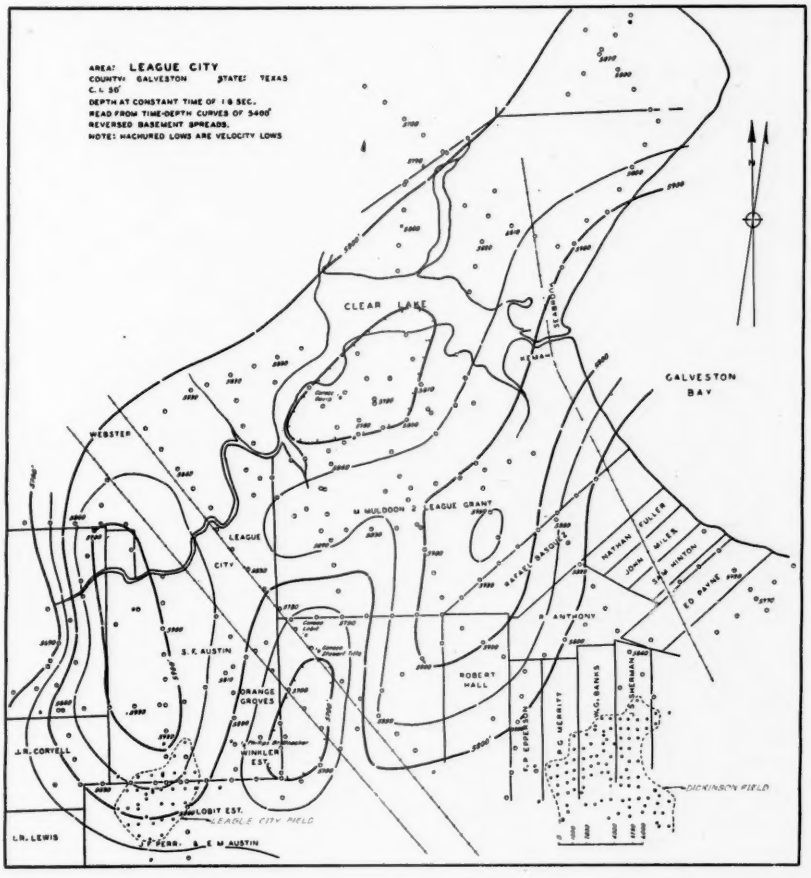


FIG. 2. Velocity distribution at a time datum of 1.6 seconds, as derived from 5400 foot reversed basement spreads, League City area, Galveston Co., Texas. Contour interval is 50 feet.

A Time-Depth curve was drawn for each profile, and depths corresponding to some chosen constant time picked, plotted on maps, and contoured. These maps can be considered as representative of apparent velocity variation to a time datum, and are similar to the "Isotime" maps of Hafner.[1] Chiefly for experimental purposes, a seismic structure map was usually prepared by applying the velocity information to dips previously computed in the normal manner.

[1] W. Hafner, "The Seismic Velocity Distribution in the Tertiary Basins of California," Seismological Society of America Bulletin, Vol. 30, No. 4, (Oct., 1940).

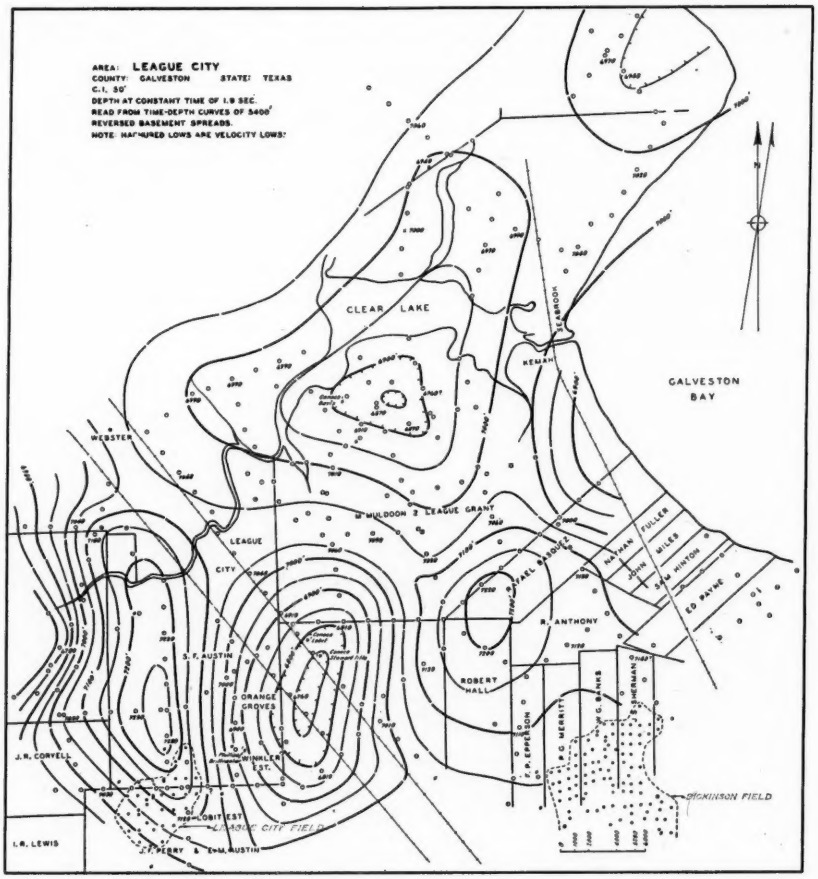


FIG. 3. Velocity distribution at a time datum of 1.9 seconds, as derived from 5400 foot reversed basement spreads, League City area, Galveston Co., Texas. Contour interval is 50 feet.

No attempt was made to grade the individual determinations on the maps. For the purpose of this paper it was thought that the attitude of contours resulting from a large number of determinations distributed over an area should be a more direct approach to the problem.

There are of course many ways of applying velocity information to seismic structure maps. The method used here attempts to make use of areal distribution of velocity to a *Time* datum. Perhaps a more desirable method would involve use of a geologic marker or any reflecting horizon on which correlations were possible. This is a more

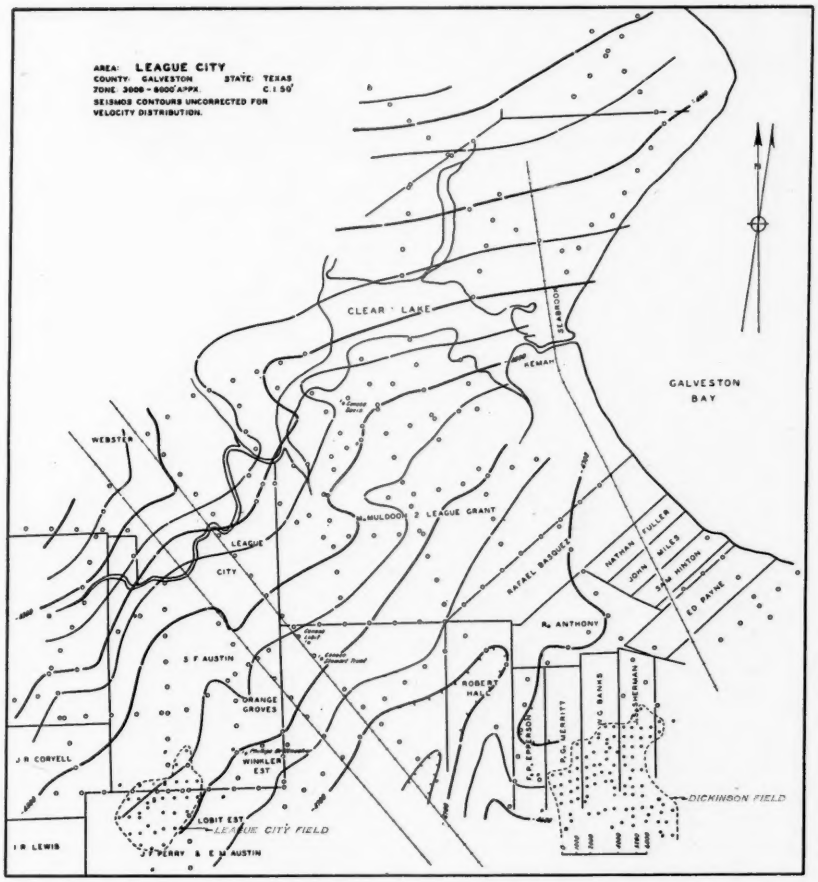


FIG. 4. Uncorrected seismic contours of a phantom horizon in the zone 3000–6000 feet, League City area, Galveston Co., Texas. Contour interval is 50 feet.

complex procedure in the area in question, however, so the simpler approach was followed. The results are presented merely for their possible interest, and no claims are made as to the value of the method used.

LEAGUE CITY AREA, GALVESTON COUNTY

In Fig. 1 is shown a typical Time-Depth curve as determined by a 0 to 5400 foot reversed basement velocity profile. Also shown is a similar curve from a velocity survey of a well in an adjacent area. It will be noted that the depth at 1.8 seconds as shown by the velocity

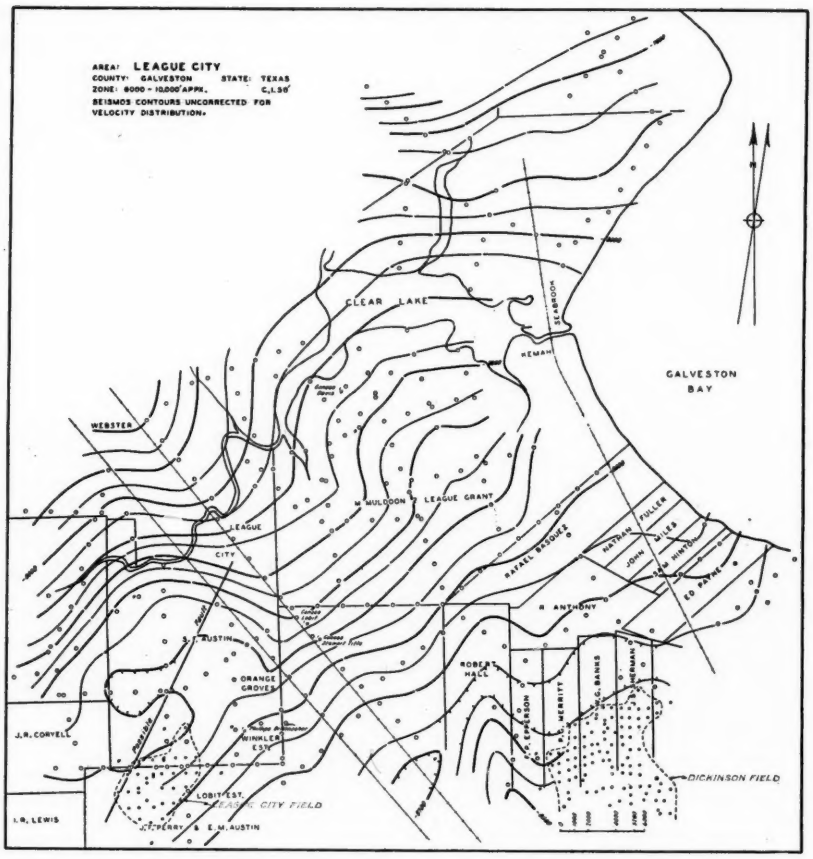


FIG. 5. Uncorrected seismic contours of a phantom horizon in the zone 6000–10,000 feet, League City, Galveston Co., Texas. Contour interval is 50 feet.

profile is about 250 feet less than that shown by the well survey. This should not be taken, however, as a direct indication of the error involved, since the surface profile location is in a down-dip position with respect to the well survey.

In Fig. 2 is shown the velocity distribution at a time datum of 1.6 seconds. Fig. 3 is the same type of map at a datum of 1.9 seconds. The similarity of the two maps is quite apparent, the deeper beds showing the greater velocity variation.

In Figs. 4 and 5 the seismic structure as represented by contours of averaged dips for zones of, respectively, 3000 to 6000 feet, and 6000

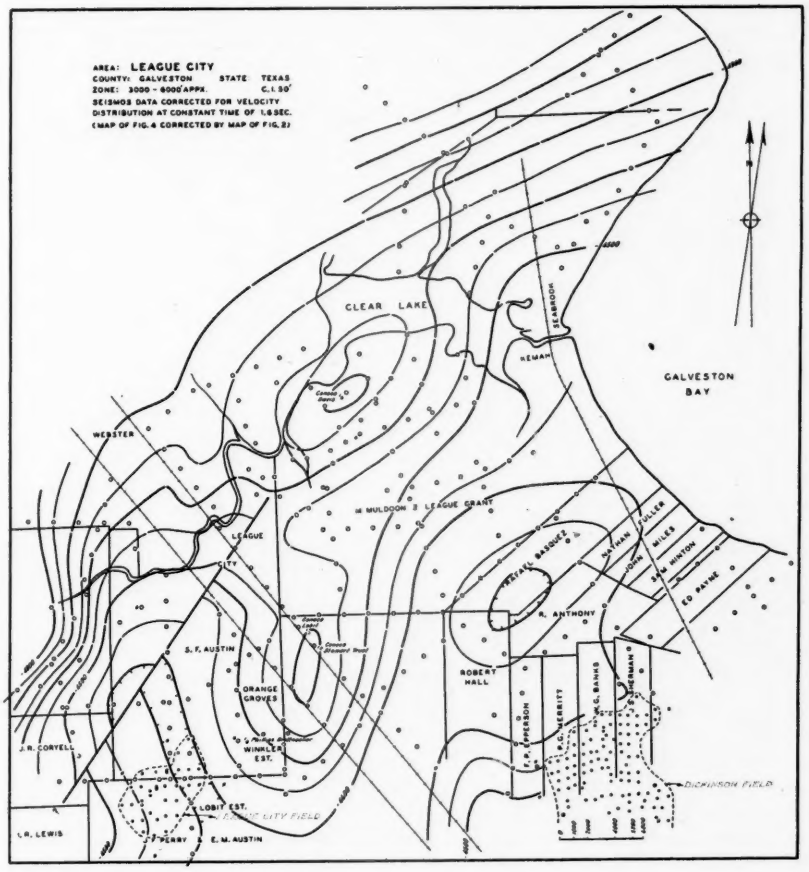


FIG. 6. Seismic contours of a phantom horizon in the zone 3000–6000 feet, corrected for the velocity distribution shown in Fig. 2. League City area, Galveston Co., Texas. Contour interval is 50 feet.

to 10,000 feet, is shown. The contour interval is 50 feet. Dips were computed and averaged, using a constant velocity for each zone to convert times to feet. All shooting was of the continuous reversed profile type, with spread lengths usually 1800 feet.

Fig. 6 shows the seismic contours of Fig. 4 corrected for the velocity distribution shown in Fig. 2. Fig. 7 is a similar map of the deeper structure—the map of Fig. 5 corrected for the velocity distribution shown in Fig. 3. As to be expected, the closed velocity lows, one just south of Clear Lake, north central part of the map, and the other northeast of

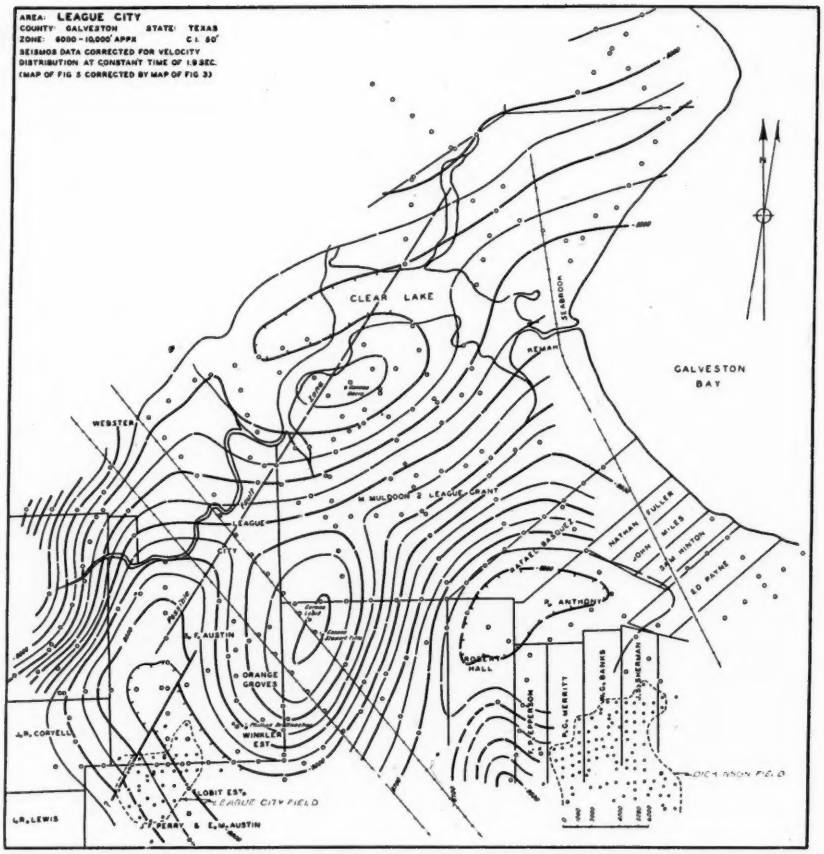


FIG. 7. Seismic contours of a phantom horizon in the zone 6000–10,000 feet, corrected for the velocity distribution shown in Fig. 3. League City Area, Galveston Co., Texas. Contour interval is 50 feet.

the League City field, southwest part of the map, convert the seismic contours into closed structural highs on the corrected maps. The addition of the faults in the southwest portion of the corrected maps is an effect of the velocity distribution on the contoured interpretation.

This may seem to be manufacturing structures out of thin air; however, the subsurface map of Fig. 8, which is one of the many possible contour interpretations of *Middle Frio* structure as indicated by the various wells, shows a faulted structure to lie under the large "manufactured" seismic closure northeast of the League City field. It may be open to question whether one should rely too heavily on

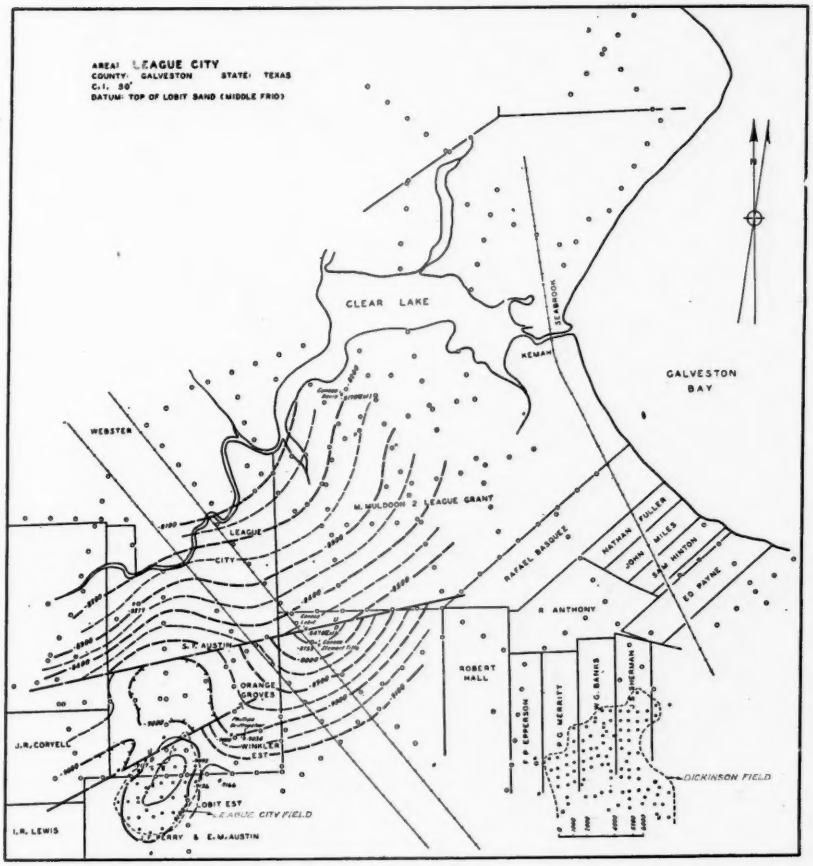


FIG. 8. Subsurface map of League City area, Galveston Co., Texas, contoured on the top of the Lobit (*Middle Frio*) sand. Contour interval is 50 feet.

this apparent relationship, but nevertheless it demonstrates what certainly may and perhaps does happen to some degree.

Although it can well be argued that faults not detected by the seismograph survey are actually responsible for the failure of the uncorrected dip map to check the subsequent well data, it should be noted that the velocity distribution as mapped is of such a nature as to improve the tie. Referring to Fig. 8, it is seen that on the *Middle Frio* "Lobit" sand the Conoco #1 Stewart Title well is 281 feet higher than the Phillips #1 Brittnacher located immediately northeast of the League City field. In Fig. 5, the uncorrected dip map, the relative

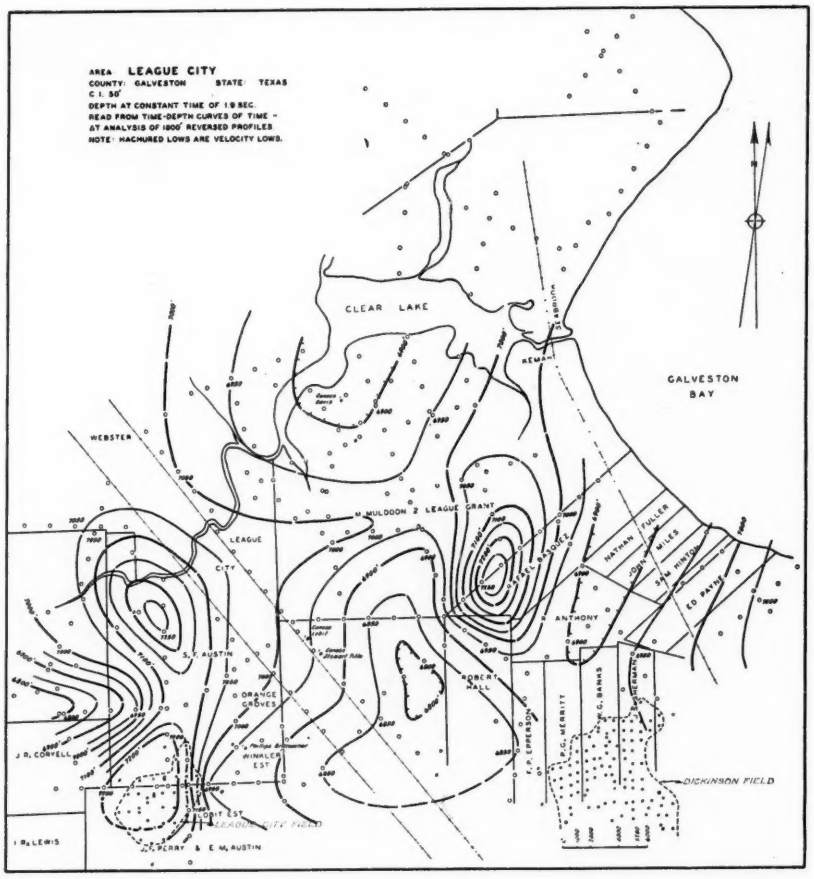


FIG. 9. Velocity distribution at a time datum of 1.9 seconds, as derived by Time-Δt analysis of 1800 foot reversed spreads, four spreads being used for each determination. League City area, Galveston Co., Texas. Contour interval is 50 feet. Compare with Fig. 3.

relief is seen to be only 100 feet between these two wells. On the corrected map of Fig. 7 the relief has been increased to 200 feet between the wells. Using the same attack on the relative relief between the Continental #1 Lobit and #1 Davis wells, it is seen that the well logs show 280 feet, while the corrected and uncorrected maps show 160 and 200 feet respectively.

Additional evidence of a deep-seated basement high here is indicated by the rapid thinning of sediments toward the bottom of the hole in the Continental #1 Lobit well on the upthrown side of the fault.

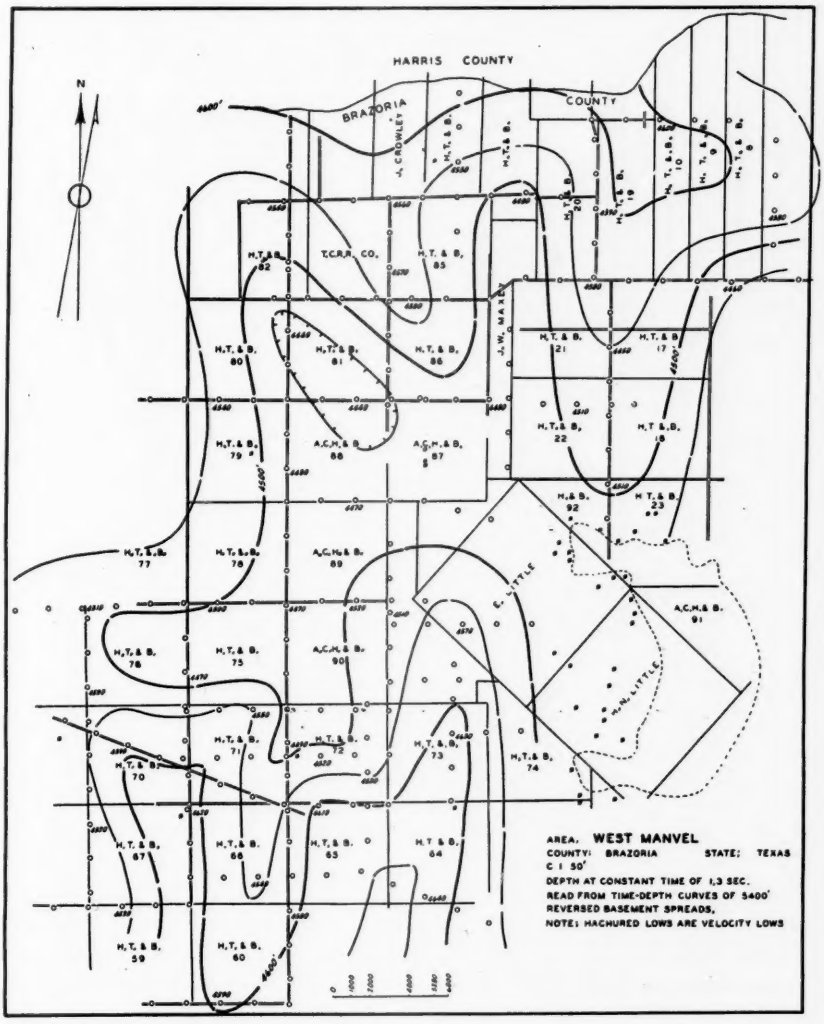


FIG. 10. Velocity distribution at a time datum of 1.3 seconds, as derived from 5400 foot reversed basement spreads, West Manvel Area, Brazoria Co., Texas. Contour interval is 50 feet.

There was little evidence from the seismic work, done at about the time the League City field was discovered, to indicate the fault which was cut by the last mentioned well, although evidence was noted of other possible faults shown in Figs. 5, 6 and 7.

In comparing the subsurface map of Fig. 8 with the velocity dis-

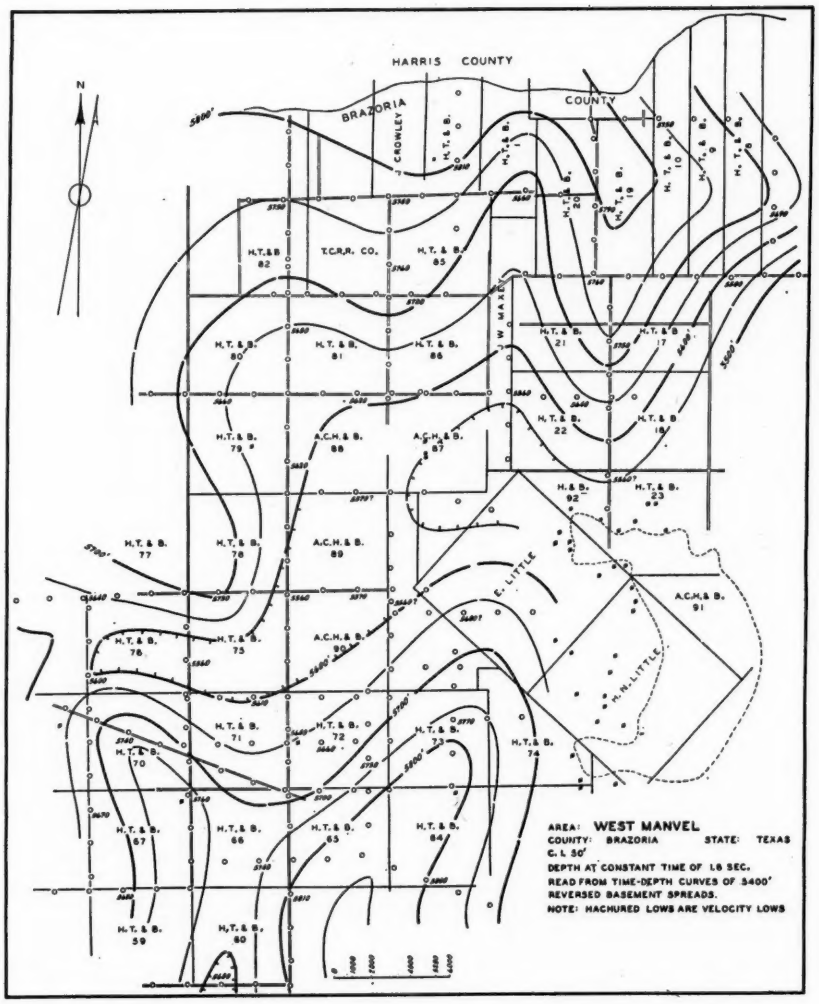


FIG. 11. Velocity distribution at a time datum of 1.6 seconds, as derived from 5400 reversed basement spreads, West Manvel area, Brazoria Co., Texas. Contour interval is 50 feet.

tribution shown in Figs. 2 and 3, as previously indicated, the large velocity low northeast of the League City field and the prominent faulted structure seem to be related. Also it should be noted that the contours place the League City field proper on a velocity high trend, while Dickinson is outside the velocity control points and nothing can be said as to the relation there.

Fig. 9 is a map showing the velocity distribution at a time datum

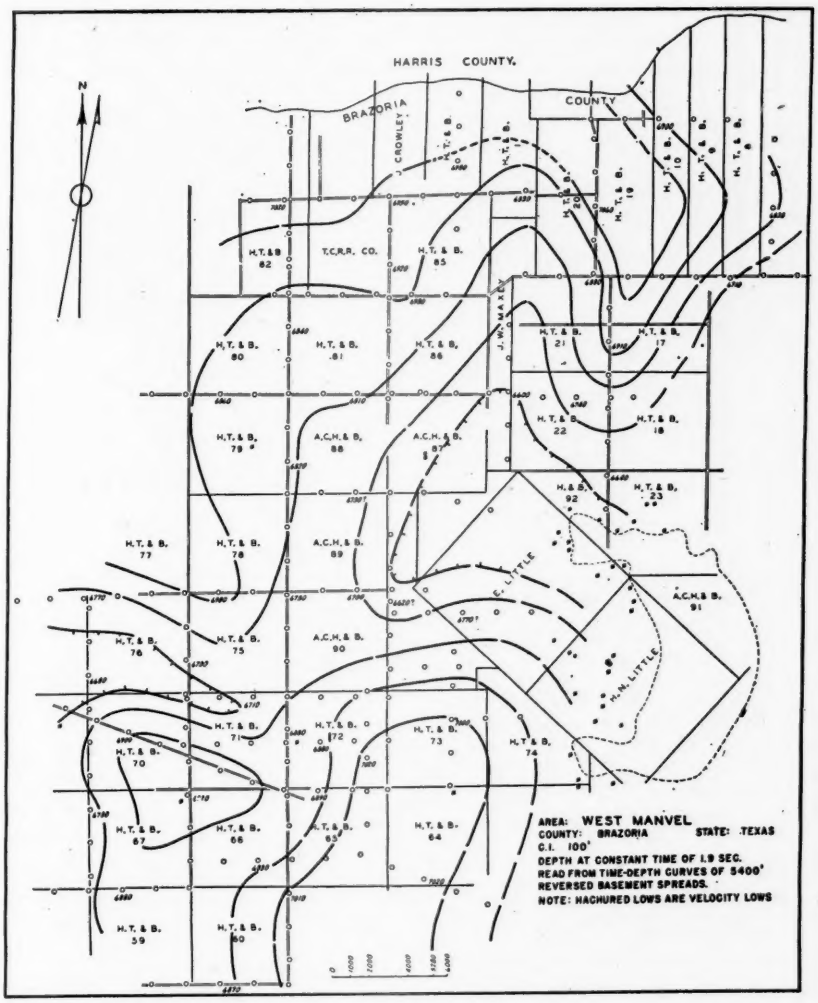


FIG. 12. Velocity distribution at a time datum of 1.9 seconds, as derived from 5400 foot reversed basement spreads, West Manvel area, Brazoria Co., Texas. Contour interval is 100 feet.

of 1.9 seconds as indicated by Time-Δt analysis of 1800 foot reversed spreads, four such spreads being used for each determination. It will be noted that in comparing this map with that of Fig. 3, the general features are similar, although the prominent velocity low northeast of the League City field has been shifted eastward by the Δt analysis determinations, and the amount of closure lessened. The slightly different distribution of the determinations between the two maps may

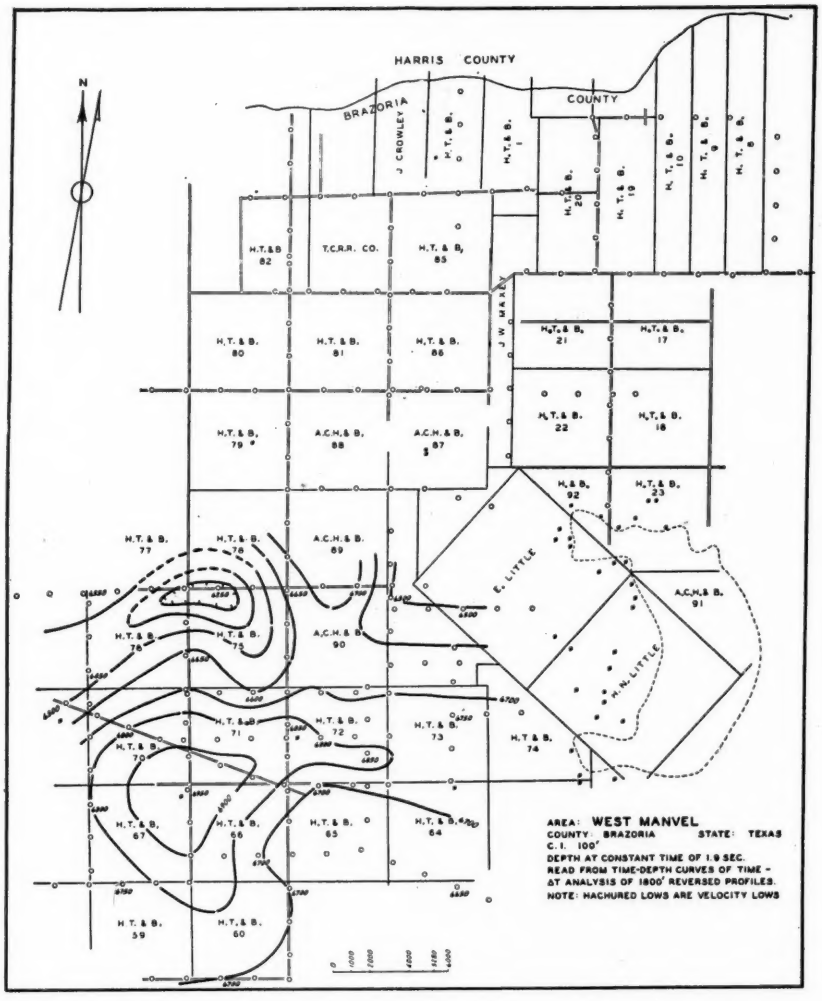


FIG. 13. Velocity distribution at a time datum of 1.9 seconds, as derived by Time-Δt analysis of 1800 foot reversed profiles. West Manvel area, Brazoria Co., Texas. Contour interval is 100 feet. Compare with Fig. 12.

account for some but certainly not all of this. In comparing 27 common points on these two maps it is found that the Time-Δt analysis velocities average 77 feet per second slower than those from the longer profiles. Considering the errors inherent in each determination and the comparatively small number of observations, this difference of only one per cent in overall velocity seems more or less accidental. However, this bears out the writer's conclusions, after making a num-

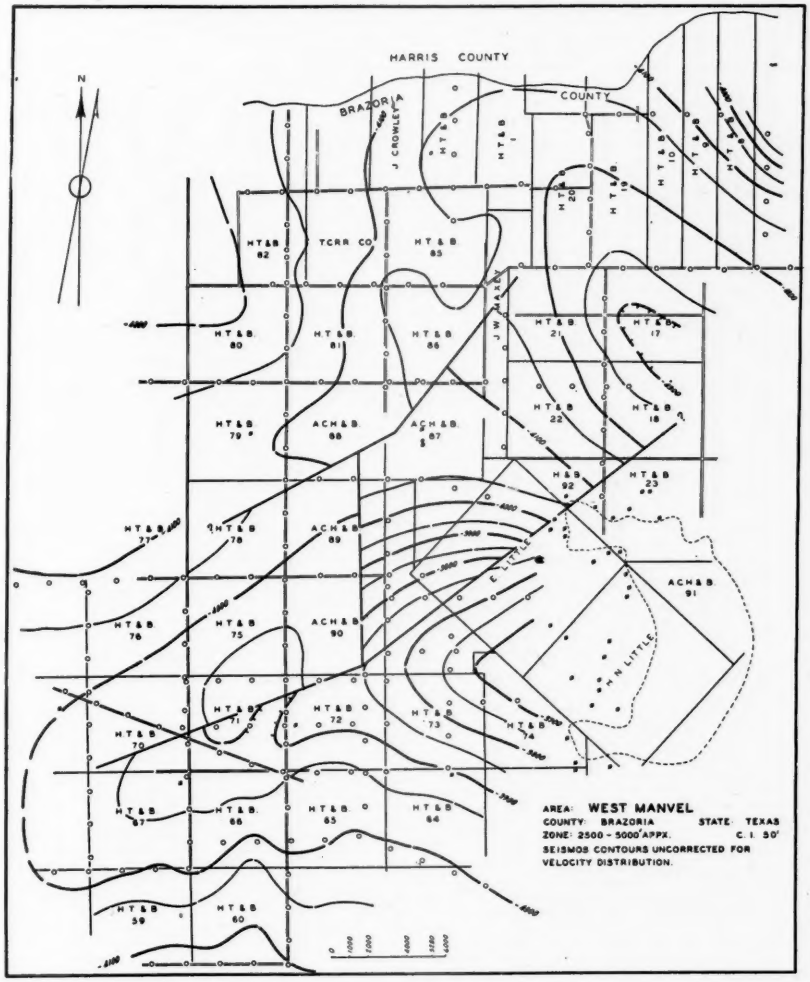


FIG. 14. Uncorrected seismic contours of a phantom horizon in the zone 2500–5000 feet, West Manvel area, Brazoria Co., Texas. Contour interval is 50 feet.

ber of such comparisons in various areas, that, "In velocity determinations from surface shooting, the longer spreads tend to give higher velocities than do the shorter spreads."

WEST MANVEL AREA, BRAZORIA COUNTY

In Figs. 10, 11, and 12, the contoured velocity distribution at a time datum of 1.3, 1.6, and 1.9 seconds, respectively, is shown. The contour interval is 50 feet on the first two and 100 feet on the third.

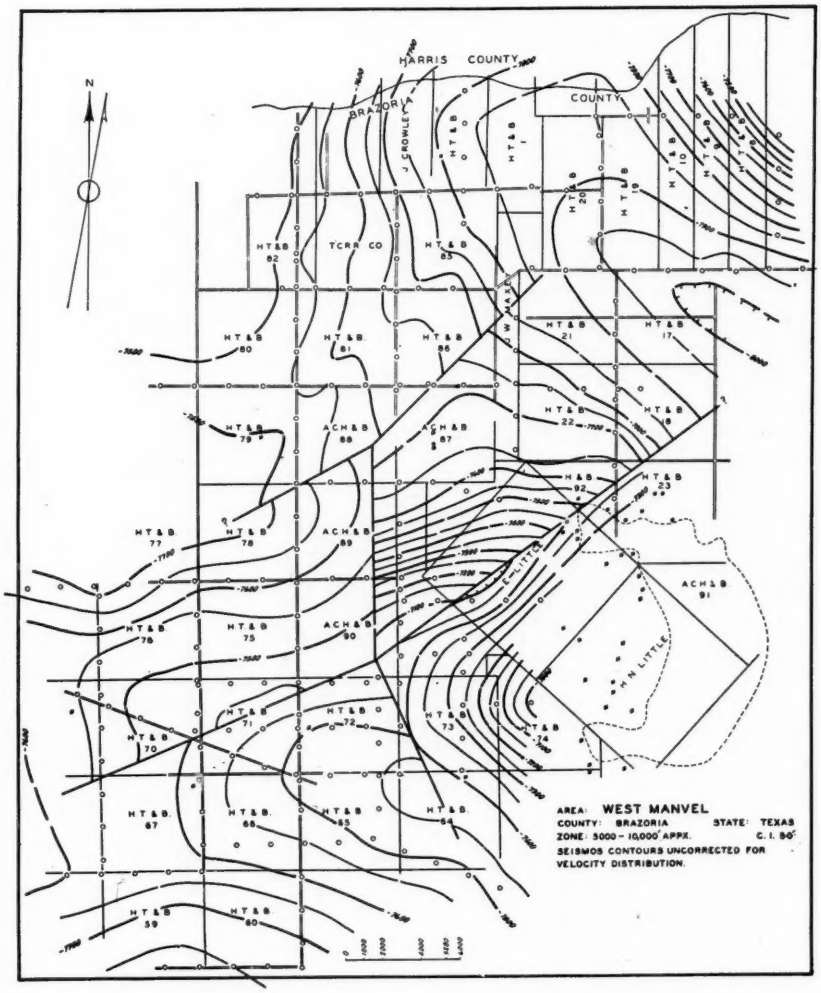


FIG. 15. Uncorrected seismic contours of a phantom horizon in the zone 5000–10,000 feet, West Manvel area, Brazoria Co., Texas. Contour interval is 50 feet.

The determinations were made from 0 to 5400 foot reversed basement spreads, as was the case in the League City area. The chief feature here is the prominent velocity low through the central part of the area, with high areas building up to the south and north. Except for minor details and the increased gradient with depth, the three maps present very much the same picture.

Fig. 13 shows the velocity distribution at the 1.9 second datum of the south one-half of the area as determined by Time-Δt analysis in

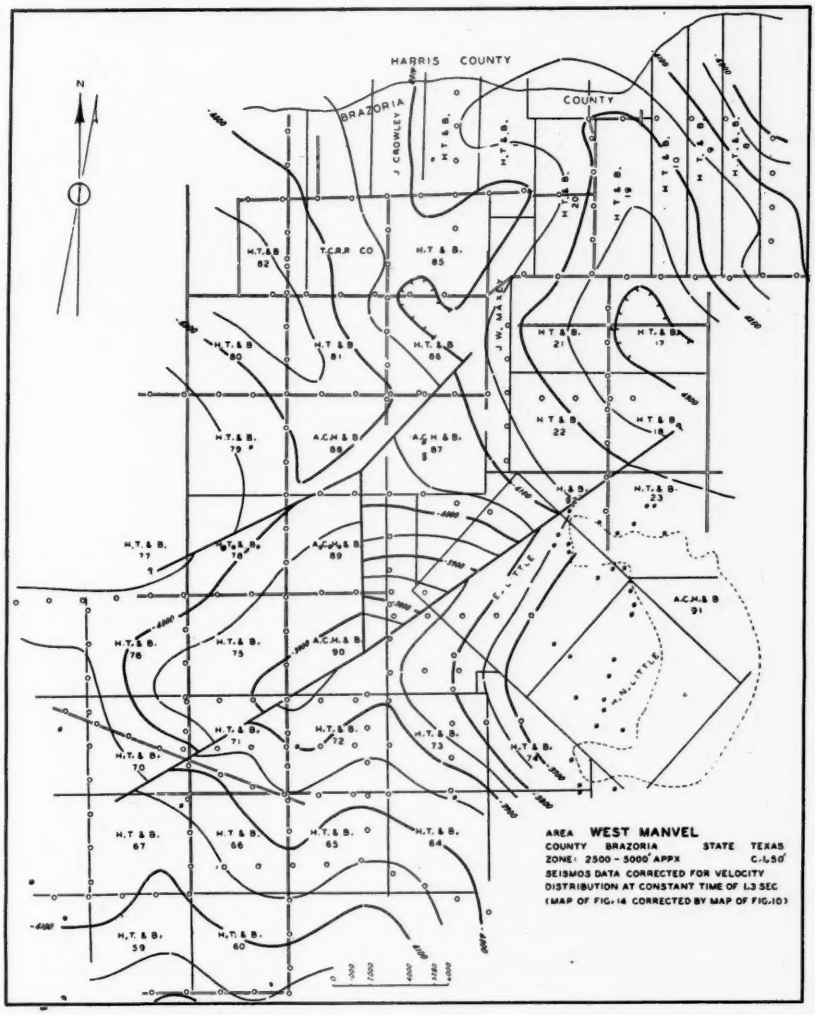

HARRIS COUNTY
BRAZORIA COUNTY
N
T.C.R.R. CO
AREA WEST MANVEL
COUNTY BRAZORIA STATE TEXAS
ZONE: 2500 - 5000' APPX C.I.50'
SEISMOS DATA CORRECTED FOR VELOCITY
DISTRIBUTION AT CONSTANT TIME OF 1.3 SEC
(MAP OF FIG. 14 CORRECTED BY MAP OF FIG. 10)

FIG. 16. Seismic contours of a phantom horizon in the zone 2500–5000 feet, corrected for the velocity distribution shown in Fig. 10. West Manvel area, Brazoria Co., Texas. Contour interval is 50 feet.

the same manner as in Fig. 9. This was done to afford a check on the velocity high in the southwest part of the area. As may be seen in a comparison with Fig. 12, the check is very good. The sharp low in Section 75 may be discounted somewhat because of lack of supporting values.

Again a comparison of the total average velocity represented by

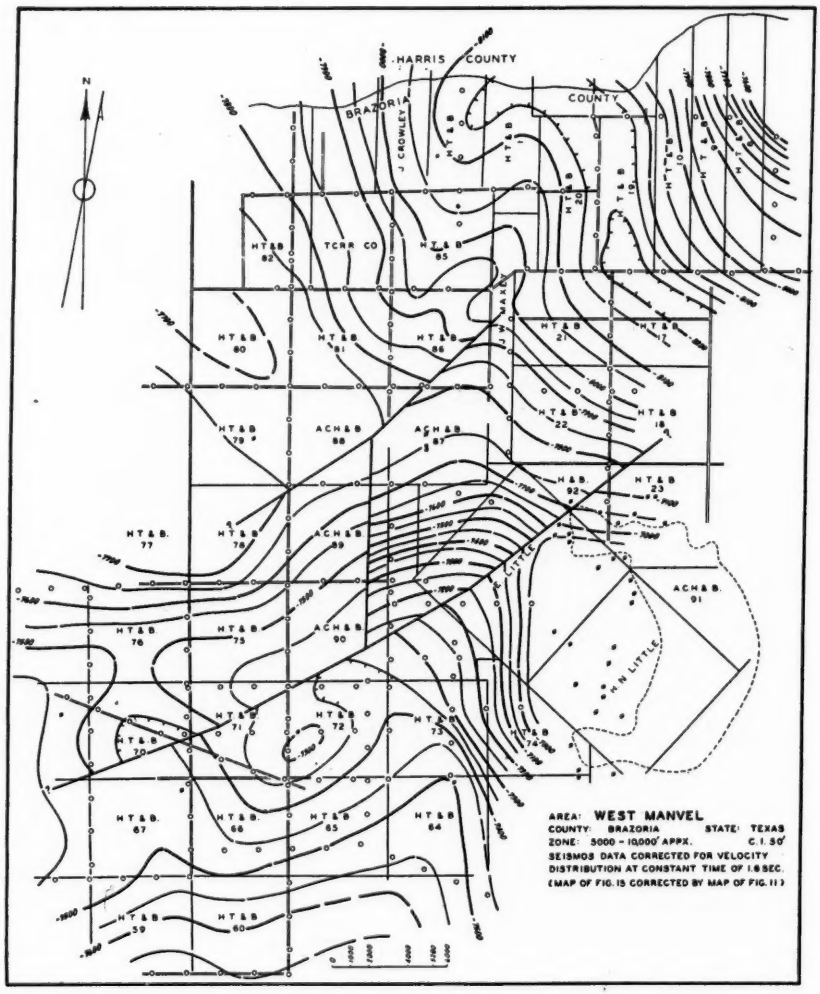


FIG. 17. Seismic contours of a phantom horizon in the zone 5000–10,000 feet, corrected for the velocity distribution shown in Fig. 11. West Manvel area, Brazoria Co., Texas. Contour interval is 50 feet.

these two types of determinations, 22 common points, shows that the Time-Δt analysis of the shorter spreads gives the slower velocity by 182 feet per second, or about $2\frac{1}{2}$ per cent.

In Figs. 14 and 15 are shown the seismic contours, uncorrected for velocity distribution, of a zone from 2500 to 5000 feet and a zone from 5000 to 10,000 feet, respectively. Dips on which these contours are

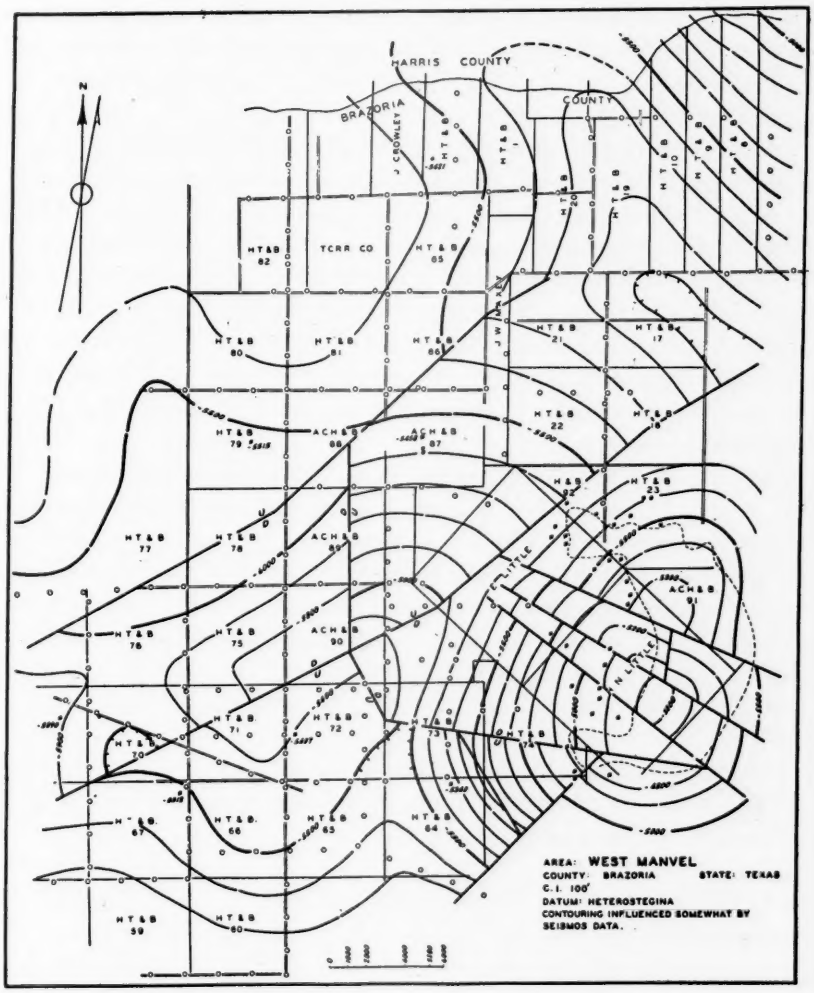


FIG. 18. Subsurface map of the West Manvel area, Brazoria Co., Texas, contoured on the *Heterostegina*, but with the contouring in the absence of well control influenced by the seismic data.

based were computed in the usual manner and averaged into the two zones.[2] Both record quality and contouring convenience serve to locate

[2] The sub-sea values assigned to the contours on these maps, as well as to those in Figs. 4, 5, 6, 7, 16, 17, and 20, are "phantom" in nature, and are not to be used as absolute values in comparing corrected and uncorrected maps. Neither are the values continuous on opposite sides of faults not completely delineated by the seismic survey.

the various faults shown. The Mykawa field is a short distance off the northeast corner of the map, and the approximate outline of production at Manvel is shown by the irregular dotted line in the east-central portion of the map.

Figs. 16 and 17 show the seismic contours corrected for the velocity distribution. Although the general appearance remains the same, it is seen that the pronounced velocity high in the south central part of the area has shifted the structural high westward in Fig. 17, and also made unnecessary the fault through Sections 64 and 73 of Fig. 15. As an examination of *Heterostegina* points on the various dry holes in the area will show, neither map correctly indicates the structural relief in all cases. The uncorrected map is better in this respect than the other. No map was prepared with the seismic data restricted to the *Heterostegina* horizon alone.

In Fig. 18 is one interpretation of the *Heterostegina* subsurface of the area. The contouring between well control points has been influenced somewhat by the seismic data, especially as to the position of certain of the faults. Keeping in mind this fact, there is some doubt as to the actual relation of the apparent similarity of the velocity low area and the area between the two parallel northeast-southwest faults. The assumption does seem justified, however, that there is some real connection between the two, whether it be through the basic seismic data[3] or from a structural angle.

The contours as shown in Figs. 10, 11 and 12 suggest that both Mykawa and Manvel may lie in low velocity areas. Lack of data makes this only a suggestion, however.

SOUTH MARKHAM AND BLESSING AREAS, MATAGORDA COUNTY

Since this area was shot as two or three separate projects with accompanying changes in technique, determinations are from both 0 to 4500 foot reversed surface, and 0 to 5400 foot reversed basement spreads. The two types are not distinguished on the maps, as a careful examination seemed to indicate that this factor had little bearing on the final results.

In Fig. 19 is shown the velocity distribution at a time datum of 2.2 seconds. Contours are at an interval of 100 feet and, if taken literally, indicate a very irregular velocity pattern. Especially prominent are: (1) the long velocity low in the northern part of the area;

[3] By this is meant that the Δt information from the records is used in both velocity and dip computations at any particular location, and therefore might result in anomalous values for both the dips and the velocities.

(2) the velocity high and adjacent lows near the Blessing field, west central part of the map; and (3) the velocity increase to the north away from the West Citrus Grove field. It is unfortunate that determinations were not secured to support the sharp velocity low at what is now the Blessing field. Unsupported, this lone point must be questioned, along with any tempting suggestions as to the relation of the low to the field.

Fig. 20 is a map showing a contoured interpretation of the normal seismic dip data averaged for the 6000 to 11,000 foot zone. As in the Manvel area, record quality and contouring convenience account for the numerous faults shown. It will be noted that the gentle faulted structure in the John Partin Survey falls within a velocity low shown in Fig. 19. The same is true of the seismic high in the J. Filly and P. Burnett Surveys, while the structure in the J. Updike Survey is at a velocity high. There seems to be a possibility that other of the faults may be related to some of the isolated velocity lows.

No map was prepared showing normal seismic data corrected for the velocity distribution in this area; however, it is obvious that the effects would be quite pronounced. Closure on the gentle faulted structures in the north part of the area, located in velocity lows, would be increased, and the Blessing structure shifted southward. Taken literally, all the closed velocity lows would tend to produce structural highs and the velocity highs to produce structural lows.

Fig. 21 is a contoured interpretation of *Frio* subsurface points at the various scattered wells. No attempt was made to show the details of the fields. Seismic dips have been used to a great extent in the areas barren of well control, which makes a critical comparison with the seismic map of little value. It is to be noted, however, that reasonable contouring of the two types of data on one map is quite possible. The Blessing field structure seems slightly displaced to the north on the seismic map, possibly due to insufficient shooting, although a critical examination will show the displacement to be much less than it looks on this map.

Fig. 22 is a Time-Depth curve of a velocity survey in a nearby well, with one obtained from two 0 to 4500 foot reversed surface profiles. The outstanding feature is the abrupt velocity decrease at about 1.6 seconds' time on each curve. Again these two curves cannot be compared directly as to the velocities and depths they represent because of the difference in location; however, the similarity of shape does seem significant. It is of interest to report that practically all of the velocity determinations made in this area give Time-Depth curves

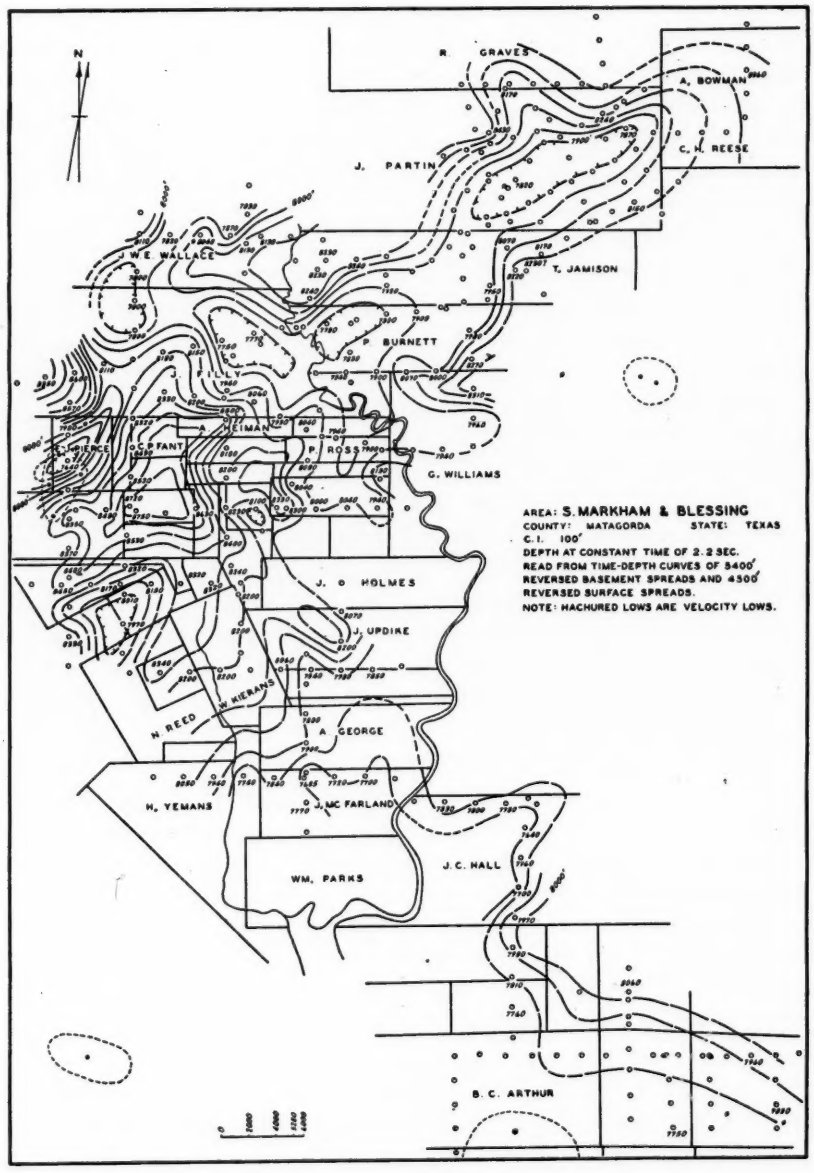


FIG. 19. Velocity distribution at a time datum of 2.2 seconds, derived from 5400 foot reversed basement spreads and 4500 foot reversed surface spreads, South Markham and Blessing area, Matagorda Co., Texas. Contour interval is 100 feet.

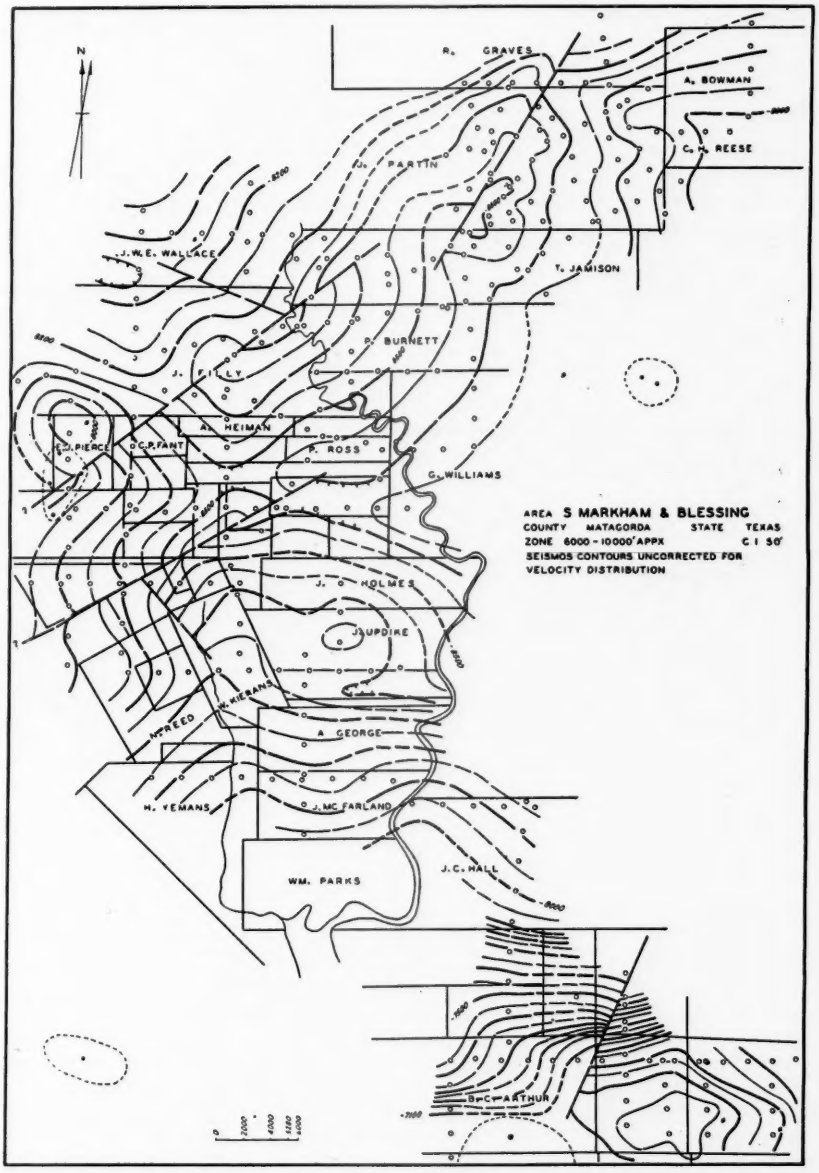


FIG. 20. Uncorrected seismic contours of a phantom horizon in the zone 6000–10,000 feet, South Markham and Blessing area, Matagorda Co., Texas. Contour interval is 50 feet.

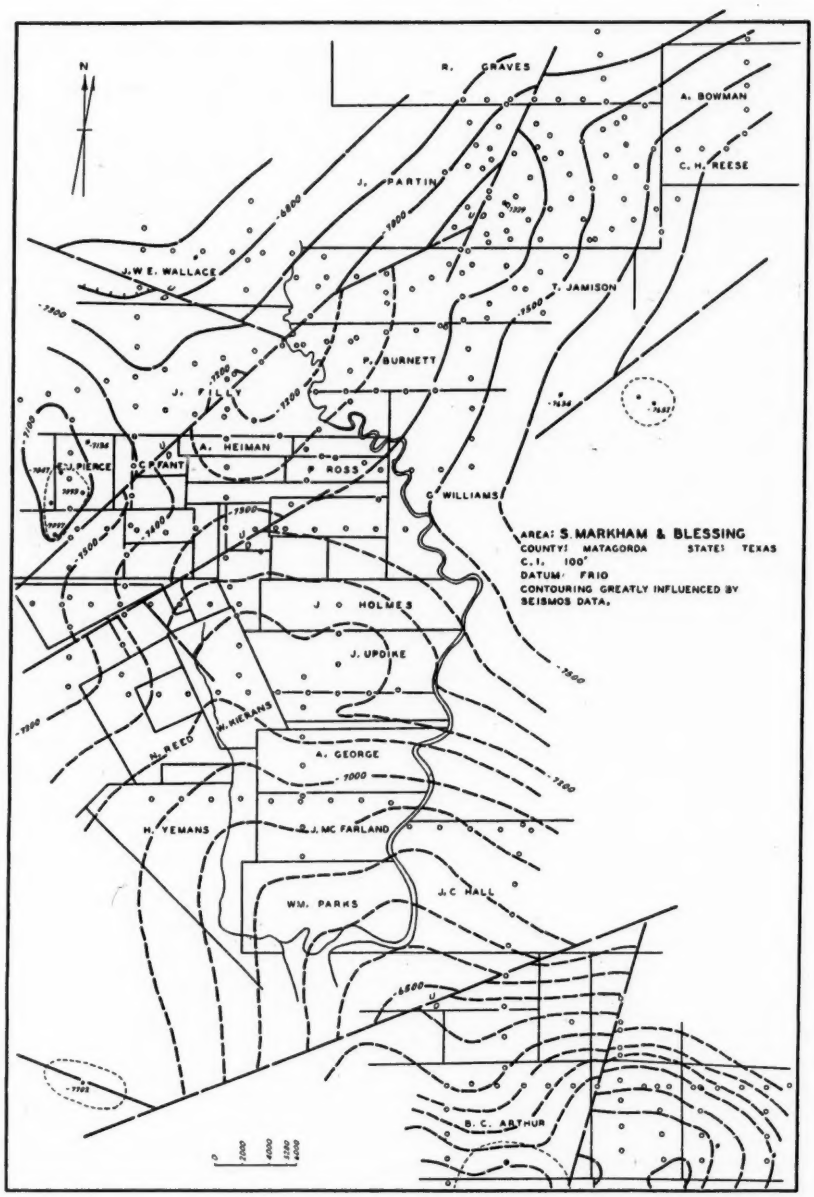


FIG. 21. Subsurface map of the South Markham and Blessing area, Matagorda Co., Texas, contoured on the *Frio*. Contouring greatly influenced by seismic data. Contour interval is 100 feet.

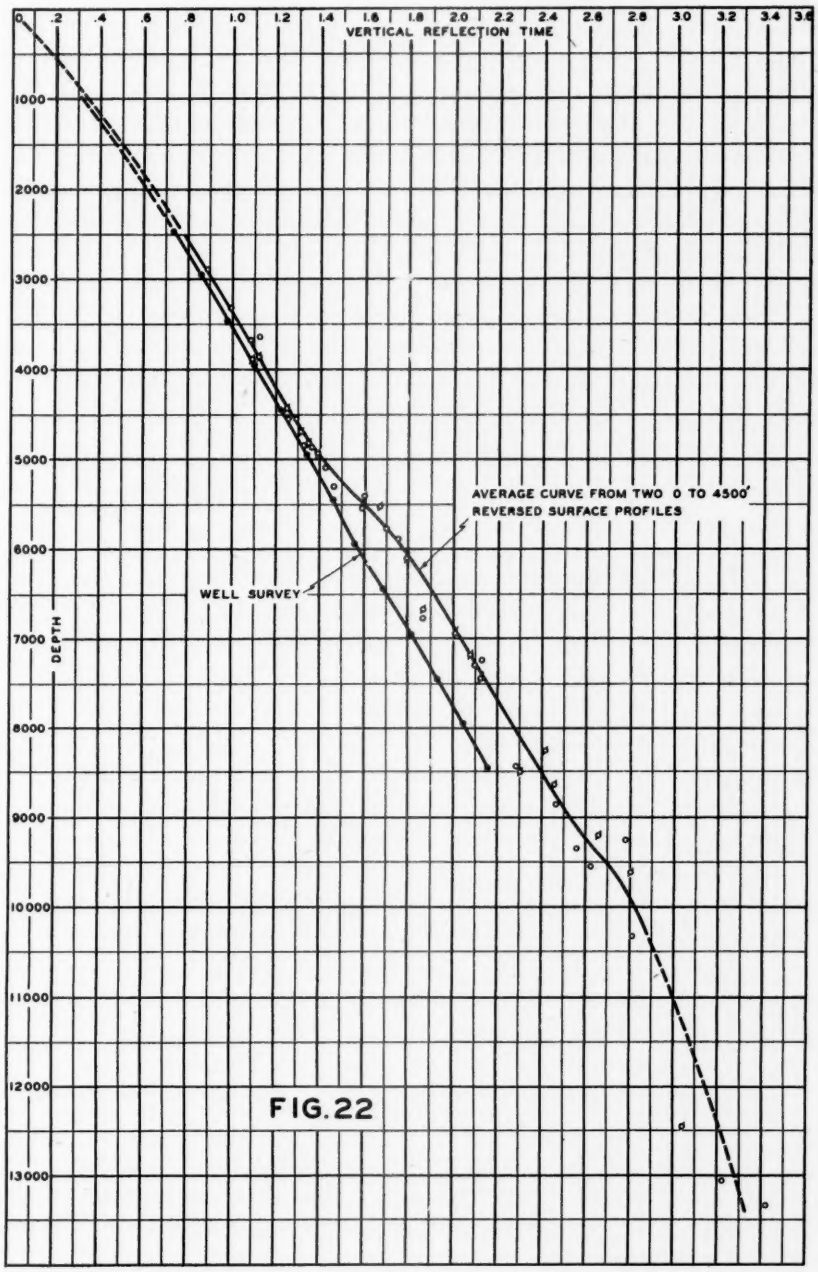


FIG. 22. Time-Depth curve as determined from two 0–4500 foot reversed surface profiles (open circles), and Time-Depth curve obtained in a velocity survey in a nearby well (solid circles). South Markham and Blessing area, Matagorda Co., Texas.

of this same characteristic shape. The additional inflection point at about 2.6 seconds is also characteristic of other curves in the area, although less significance is attached to it because of the wider scattering of points at the greater depth and lack of a definite subsurface tie.

The log of the well in which this velocity survey was made shows the inflection point at about 6000 feet to be the top of the *Marine Oligocene*. The fact that this section is here mostly shales, while the *Miocene* immediately above is chiefly sands, is thought to be the proper explanation of the inflection in the curve.

This phenomenon was noticed and properly interpreted in the curves from the surface velocity profile shooting by the field crew in routine procedures, and without previous knowledge of the well survey data. This seems significant, especially since the usual tendency is to smooth out the curves as much as possible and to discount points that do not fit as being due to errors inherent in the method.

SUMMARY

1. Data from three Texas Gulf Coast projects show that velocities determined from long reversed reflection profiles and from Time-Δt analyses of shorter profiles are quite variable over local areas, but can be contoured into fairly regular patterns. If applied to the ordinary seismic data profound changes in structural interpretation are effected. The evidence presented does not indicate the validity of such a procedure, nor is it necessarily condemned.

2. Velocities determined from long reversed reflection profiles in Matagorda County, when plotted as Time-Depth curves or as some other function of time or depth, may indicate clearly major discontinuities in velocity stratification. In the example presented, one such discontinuity is definitely identified as the *Miocene-Oligocene* contact.

3. In two areas it is shown that velocities obtained from 5400 foot reversed reflection profiles are higher than those obtained by Time-Δt analysis of 1800 foot reversed profiles. There is noted, however, a general agreement in the contoured areal distribution.

4. Velocity anomalies determined from surface profile shooting may be associated with faulting in the subsurface beds.

The author wishes to acknowledge his gratitude to the Continental Oil Company for permission to publish this paper, and his appreciation of the original work of C. A. Putnam and R. W. Carson in securing the field data.

AN ANALYTICAL METHOD OF MAKING WEATHERING CORRECTIONS*

M. B. DOBRIN†

ABSTRACT

A method of weathering is described by which intercept times can be rapidly and accurately computed from first arrival times without the plotting of time-distance curves. The velocities are determined by a mechanical procedure, based on least squares theory, which normally requires no exercise of judgment on the part of the computer. The application of the method to actual field set-ups is illustrated by sample calculations.

INTRODUCTION

In the conventional method of determining seismic weathering corrections from intercepts on first arrival time curves, it is necessary to ascertain the velocity of seismic waves in the first high-speed zone beneath the weathered layer. This is generally done by plotting the first arrival times against the shot-detector distance and estimating the speed from the slopes of the curves thus obtained. The usual procedure for determining these slopes is graphical and consists in averaging the deviations by eye of each plotted point from the best line that could be drawn through them all.

This subjective process is often difficult and time-consuming, since in most cases it involves the use of trial-and-error methods. A computer, for this reason, must have had considerable experience before he can make reliable weathering corrections for records shot in country with any but the most straightforward surface conditions.

The use of standard least square methods for determining the best line through a series of points would remove this undesirable subjective factor from the weathering calculation, but these are generally so laborious that they would not be practical for routine work. However, by utilizing certain characteristics of ordinary reflection or refraction set-ups, such as the regular spacing of detectors and the coincidence of detector positions for shots from opposite directions, a least squares method can be set up which enables the whole weathering calculation to be performed mechanically and which is also more rapid and accurate than the ordinary procedure. By this method it is possible to calculate the intercepts directly from the first arrival times and the

* Presented at the Spring 1942 meeting, Denver, Colorado.

† Gulf Research and Development Company, Pittsburgh. Now at the Naval Ordnance Laboratory, Washington, D. C.

distances without the necessity of plotting the arrivals or of determining the velocity of the high-speed zone explicitly.

THEORY

The present method is based upon the principle that the relative values of the intercept times as determined by the shooting in opposite directions across a spread should be independent of the direction of shooting. If there is no weathering or equal weathering under the shot points at opposite ends of a reverse spread the intercept times at each

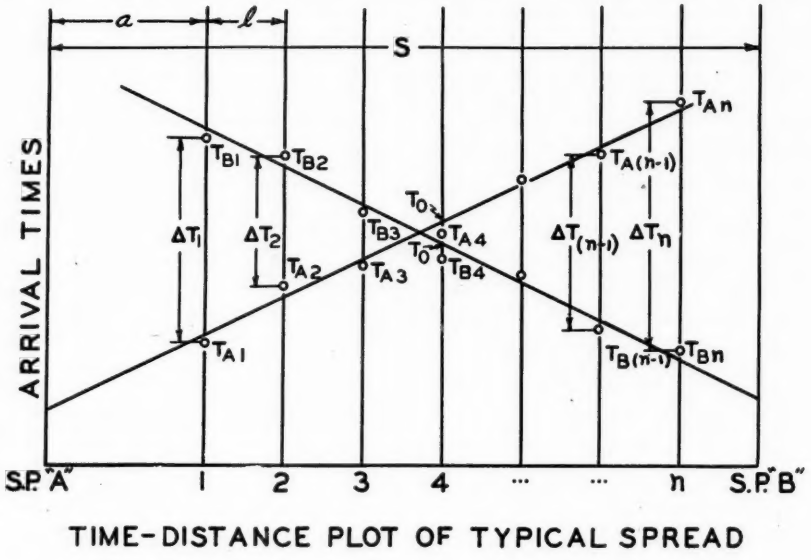


FIG. 1. Time-distance diagram of a typical spread.

detector position should be identical for the two shots. If there is unequal weathering, the two intercept times at each detector position should differ by constant amounts.

In the analytical procedure which forms the basis for this method, the velocities are determined by performing simple arithmetical operations, such as multiplying by small digits, upon the differences, at each detector, between the arrival times associated with the two shots. These operations effectively weight the various differential times so that each makes its proper contribution to the velocity. This quantity is not expressed directly but instead is put into the form of a time parameter, s/V, where s is the separation of the shot points at

opposite ends of the spread. From this parameter and the sum of the arrival times at each detector position, the average intercept time is computed by simple subtraction.

Fig. 1 shows a time-distance plot for a set-up of n detectors, spaced a constant distance l apart, located between the shot points A and B, which are separated by the distance s. Detector 1 is a distance a from A. The arrival times as recorded at the detectors $1, 2, \ldots n$ are to be designated as $T_{A1}, T_{A2}, \ldots T_{An}$ for shots from A and as $T_{B1}, T_{B2}, \ldots T_{Bn}$ for shots from B. The actual velocity, V, can be obtained by averaging the apparent velocities determined by the arrival times from each direction; and this can be best represented by two straight lines of slopes $1/V$ (representing the shot from A) and $-1/V$ (representing the one from B). These are the ideal time distance curves. Where the ideal curve for a shot from A crosses the point midway between detector 1 and detector n, we will designate the time as T_0. Where the line from B crosses the midpoint we will designate the time as T_0'. It is of course not necessary that this midpoint be equidistant from A and B.

Now, if at the kth detector the arrival times were to lie on these ideal lines we would have

$$\begin{aligned} T_{Ak} &= T_0 - \frac{1}{V}\left[\frac{(n-1)}{2}l - (k-1)l\right] \\ &= T_0 - (n+1-2k)l/2V \end{aligned} \tag{1}$$

theoretically. But the actual value of T_{Ak} will differ from this by an amount

$$\epsilon_{Ak} = T_{Ak} - T_0 + (n+1-2k)l/2V. \tag{2}$$

Similarly, shooting from the opposite direction

$$\begin{aligned} T_{Bk} &= T_0' + \frac{1}{V}\left[\frac{(n-1)}{2}l - (k-1)l\right] \\ &= T_0' + (n+1-2k)l/2V \end{aligned} \tag{3}$$

theoretically, and

$$\epsilon_{Bk} = T_{Bk} - T_0' - (n+1-2k)l/2V. \tag{4}$$

To determine the best velocity, V, from the plotted points we make use of least squares theory and choose V as that velocity which will make the sum of the squares of the ϵ values a minimum. That is,

$$\sum \epsilon^2 = \text{a minimum, or} \tag{5}$$

$$\sum \frac{d(\epsilon^2)}{dV} = 0 = \sum 2\epsilon \frac{d\epsilon}{dV}. \tag{6}$$

Applying (6) to (2) and (4),

$$\begin{aligned} 0 = &\sum_1^n \{T_{Ak} - T_0 + (n+1-2k)l/2V\}(n+1-2k)l/(-V^2) \\ &+ \sum_1^n \{T_{Bk} - T_0' + (n+1-2k)l/2V\}(-[n+1-2k]l/(-V^2). \end{aligned} \tag{7}$$

The T_0 and T_0' terms drop out because for each positive value of $(n+1-2k)$ there is a negative value that cancels it, so that

$$\begin{aligned} 0 = &\sum_1^n (T_{Ak})(n+1-2k)l + [(n+1-2k)l]^2/2V \\ &+ \sum_1^n (-T_{Bk})(n+1-2k)l + [(n+1-2k)l]^2/2V. \end{aligned} \tag{8}$$

Solving this for V,

$$V = -\sum_1^n (n+1-2k)^2 l^2 \Big/ \sum_1^n (T_{Ak} - T_{Bk})(n+1-2k)l. \tag{9}$$

This furnishes the velocity at the base of the weathered layer. To determine the intercept time at the kth detector for the arrival from shot point A one sets

$$b_{Ak} = T_{Ak} - [a + (k-1)l]/V. \tag{10}$$

Similarly,

$$b_{Bk} = T_{Bk} - \{s - [a + (k-1)l]\}/V. \tag{11}$$

Now the best intercept time for the kth detector location will be the average of b_{Ak} and b_{Bk}:

$$b_k = (b_{Ak} + b_{Bk})/2 = (T_{Ak} + T_{Bk})/2 - s/2V \tag{12}$$

$$= \tfrac{1}{2}(T_{Ak} + T_{Bk}) - \left\{ -\frac{s}{2l} \frac{\sum_1^n (T_{Ak} - T_{Bk})(n+1-2k)}{\sum_1^n (n+1-2k)^2} \right\}. \tag{13}$$

APPLICATION

Eq. 13 enables one to compute the intercept time for a detector location in terms of the arrival times, the number of detectors, the distance between adjacent shots, and the detector separation. In routine shooting, all of these quantities are generally fixed except for k, the ordinal detector number, and the arrival times, T_{Ak} and T_{Bk}.

Actually, the $(n+1-2k)$ terms are weighting factors which determine the relative contributions of the arrivals at each detector in the determination of the velocity. When k approaches *zero* or n, the absolute value of $(n+1-2k)$ will be greatest, indicating that those arrivals nearest the shot point are weighted most heavily in this computation.

Let us apply Eq. 13 to the determination of intercept times for the case of four detectors between the shot points. This is a common setup for a six detector spread, since the first detector is often used to record the up-hole time, and the last detector is placed at the next shot point. One evaluates the s/V term by a summation from $k=1$ to $k=n=4$.

$$\begin{aligned}\frac{1}{V} = -\{&3(T_{A1} - T_{B1}) + (T_{A2} - T_{B2}) \\ &- (T_{A3} - T_{B3}) - 3(T_{A4} - T_{B4})\}/20l.\end{aligned} \tag{14}$$

Or, rearranging terms,

$$\begin{aligned}\frac{1}{V} &= \{3[(T_{A4} - T_{B4}) + (T_{B1} - T_{A1})] \\ &\quad + [(T_{B2} - T_{A2}) + (T_{A3} - T_{B3})]\}/20l \\ &= [3(\Delta T_4 + \Delta T_1) + (\Delta T_2 + \Delta T_3)]/20l\end{aligned} \tag{15}$$

so that

$$b_k = \tfrac{1}{2}(T_{Ak} + T_{Bk}) - \frac{s}{40l}\{3[\Delta T_4 + \Delta T_1] + [\Delta T_2 + \Delta T_3]\}. \tag{16}$$

A similar calculation for the case of six detectors gives

$$\frac{1}{V} = [5(\Delta T_6 + \Delta T_1) + 3(\Delta T_5 + \Delta T_2) + (\Delta T_4 + \Delta T_3)]/70l \tag{17}$$

the intercept times being calculated as in (16) for the four-detector case.

To illustrate the application of the method, Table I is reproduced. It is the calculation that was used in the actual weathering determination for a six-trace spread, with four detectors between the shot points. Fig. 2 shows how the weathering would be carried out with the same data if the conventional method, employing a time-distance curve, were used. The intercept values indicated for each detector position on Fig. 2 agree closely with those obtained in Table I.

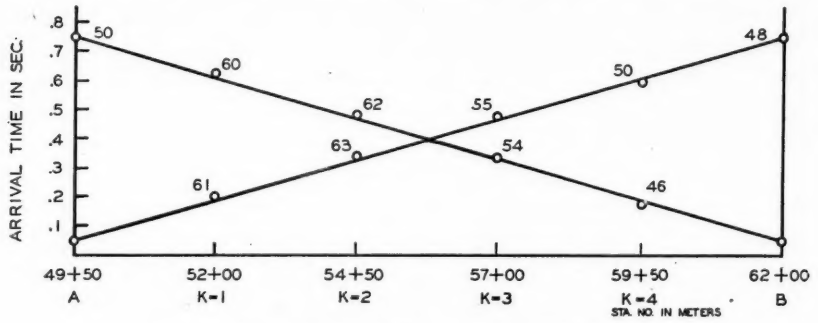


FIG. 2. Time-distance plot and conventional solution.
of weathering for the data shown in Table I.

TABLE I. EXAMPLE OF LEAST SQUARES COMPUTATION OF INTERCEPTS

k	*Shot A*	1	2	3	4	*Shot B/Order of Operation*	
Station	49+50	52+00	54+50	57+00	59+50	62+00	
b_k	50	60	63	55	47	48	(11)
$T_{Ak}+T_B-s/V$		121	127	111	94		(10)
$T_{Ak}+T_{Bk}$		835	841	825	808		(9)
T_{Ak}	59	205	351	485	620	762	(1)
T_{Bk}	764	630	490	340	188	50	(2)
ΔT_k		425	139	145	432		(3)
$\Delta T_1+\Delta T_4$		857					(4)
$3(\Delta T_1+\Delta T_4)$		2571					(5)
$\Delta T_2+\Delta T_3$		284					(6)
$3(\Delta T_1+\Delta T_4)+(\Delta T_2+\Delta T_3)$		2855					(7)
s/V		714					(8)

Times are in milliseconds

The intercept times at the two end detector positions, which are coincident with the two adjacent shot points, were obtained by subtracting the s/V value from each observed arrival time. It is of interest to observe that the velocity is nowhere used explicitly or even calculated as such. However, if the velocity is desired one merely

divides the s/V value into the length of the spread, s. If the distance between the shot on either side and the detector nearest it is changed, the calculation is not affected unless s changes also.

For the more usual cases where a larger number of detectors is employed, the numerical coefficients will be somewhat larger and more numerous. Table II gives the $(n+1-2k)$ coefficients for each set of detector positions in spreads of from four to eleven detectors. To illustrate its application for the case of ten detectors it should be noted that the outermost pair of ΔT values is multiplied by 9, the next pair toward the center by 7, etc. The last term in the table evaluates the coefficient in the numerator of equation (9).

TABLE II. COEFFICIENTS FOR ΔT VALUES IN LEAST SQUARES WEATHERING METHOD

n	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$	$k=9$	$k=10$	$k=11$	$\sum_{1}^{k}(n-1-2k)^2$
4	3	1	−1	−3								20
5	4	2	0	−2	−4							40
6	5	3	1	−1	−3	−5						70
7	6	4	2	0	−2	−4	−6					112
8	7	5	3	1	−1	−3	−5	−7				168
9	8	6	4	2	0	−2	−4	−6	−8			240
10	9	7	5	3	1	−1	−3	−5	−7	−9		330
11	10	8	6	4	2	0	−2	−4	−6	−8	−10	420

As the number of detectors increases, a point is reached where the method becomes too cumbersome to be applied conveniently. The maximum number, in practice, is to be governed by the accuracy desired in the results and in the complexity of the surface conditions in the area being worked.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the very substantial assistance given him in the development of this method by Mr. L. W. Gardner of this company who suggested many of the mathematical steps employed. Without his aid the method could not have been brought to its present stage of usefulness. Appreciation is also expressed to Mr. T. A. Elkins and Dr. L. L. Nettleton for criticizing the manuscript and to Dr. Paul D. Foote and Dr. E. A. Eckhardt for permitting publication of this paper.

AN APPLICATION OF SEISMIC SURVEYING TO THE LOCATION OF BAUXITE IN ARKANSAS*

J. A. GILLIN,† LORENZ SHOCK,† AND E. D. ALCOCK†

ABSTRACT

The exploration for bauxite has been greatly stimulated by the increased demand for aluminum. The geology of the formation of bauxite in Arkansas is closely related to the syenite exposures on the old land surface at the end of Midway time. A refraction seismic survey mapped the attitude of the high velocity formations identified as syenite or Paleozoic rocks. By combining this map with a map of the Midway from scattered core holes, a map of the old land surface at the end of Midway time was obtained. By interpreting this map, future explorations by core drills can be guided to the most favorable locations.

The increased demand for aluminum in the war program, and the lack of shipping space in which to import bauxite from South America, has greatly stimulated the exploration for new bauxite deposits in the United States. Approximately 90% of the present bauxite production in the United States comes from a small region in the central part of the state of Arkansas.[1] The deposits of bauxite in this region are usually of large size and compactly located in a small area. There are other deposits known to exist in the Southeastern states of the United States, which are being worked on a small scale. These deposits, however, are generally of small extent and rather widely scattered, hence from the standpoint of an immediate increase in our reserves, the Arkansas bauxite region offers the most promise for exploration.

The commercial bauxite deposits in Arkansas occur in Saline and Pulaski Counties near Little Rock in the central part of the state, (Fig. 1). The known deposits are confined to two small areas approximately fourteen miles apart, the Sweet Home area lying about four miles south and southeast of Little Rock and the Saline County area centered around the town of Bauxite. In both these areas the deposits lie close to an outcrop of nepheline syenite. The syenite occurs as an intrusion through the Paleozoic basement rocks. The composition of the syenite in both outcrops is identical, which might indicate that they were cupolas of the same underlying syenite mass.

* Presented at the Denver meeting, April, 1942.

† National Geophysical Company, Dallas, Texas.

[1] Bramlette. The Geology of the Arkansas Bauxite Region. Arkansas Geological Survey Information Circular No. 8.

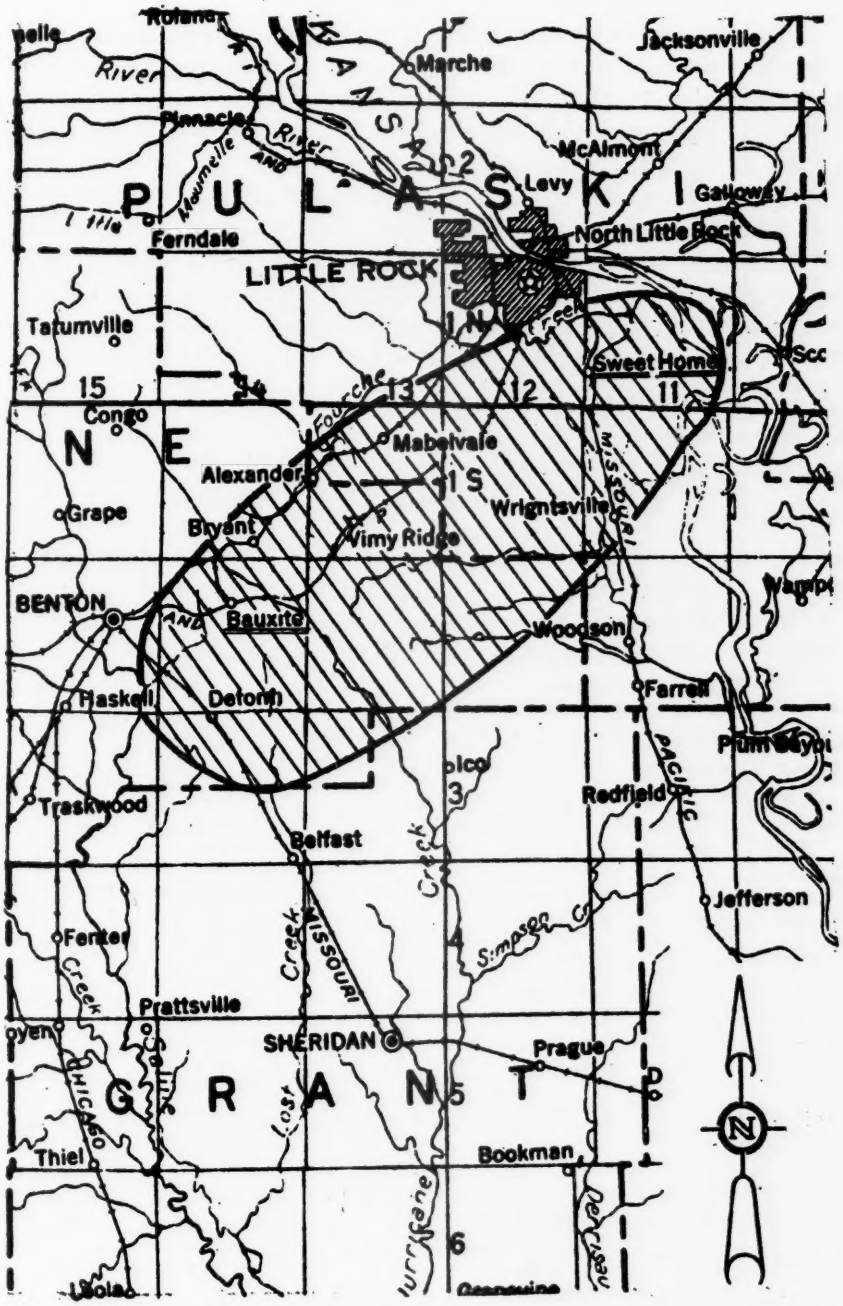


FIG. 1. Arkansas bauxite region, Grant, Saline, and Pulaski Counties, Arkansas. Known deposits are confined to the vicinities of the towns of Sweet Home and Bauxite.

In Information Circular No. 8 of the Arkansas Geological Survey, Bramlette concludes from his studies that the bauxite in Arkansas was formed as an alteration product of nepheline syenite. This theory was first developed and established as a practical working principle by W. J. Mead[2] in 1912. Bramlette's evidence also indicates that the surficial alteration took place during a single geological period, the transition period between the Midway and the Wilcox, hence, the bauxite deposits are confined to the old land surface existing during this period. Several deposits of bauxite have been found at the contact zone between the Midway and the Wilcox; however, the only commercial bauxite is that which is found lying on or near the nepheline syenite. Granting these conclusions, the major condition for the

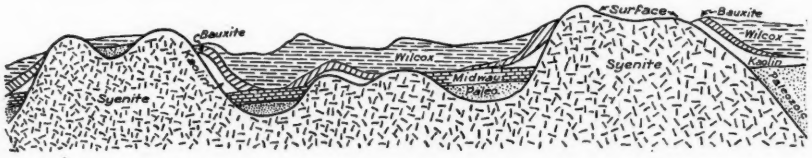


FIG. 2. Generalized cross-section of the Arkansas bauxite region, illustrating the occurrence of bauxite on or adjacent to portions of the syenite mass not overlain by Midway sediments.

presence of commercial bauxite at any location is that the nepheline syenite should have formed part of the land surface during the transitional period between the Midway and the Wilcox ages. Furthermore, since the bauxite was developed as an alteration product from the syenite through leaching by ground waters during the Midway-Wilcox interval, it follows that bauxite will be found only on or immediately adjoining syenite not covered by Midway sediments. Fig. 2 is a generalized cross-section of the Arkansas bauxite region which illustrates some of these points.

The physical characteristics of bauxite ore vary considerably and are quite similar to those of adjacent sediments, hence geophysical methods do not hold much promise for the detection of the presence of the bauxite itself. Furthermore, the quality of the ore can only be determined by chemical analysis. The only successful solution for the location of bauxite to date has been the use of a drill followed by a chemical analysis of the samples.

A map of the old land surface during the Midway-Wilcox transi-

[2] Econ. Geol., Vol. X, pp. 28–54 (1915).

tional period would be of great value, however, to the exploration program. Such a map would outline the only areas in which bauxite could have been formed and would eliminate the necessity for drilling outside these areas. This map would also indicate areas of higher probability for the presence of bauxite within the areas in which bauxite could have been formed.

The problem of mapping subsurface structures, or old land surfaces, is particularly adapted to solution by use of the seismograph. Due to the shallow depth of the surface to be mapped (not exceeding 1000 feet) the problem is more readily solved by use of the refraction seismograph than the reflection seismograph.

The velocity contrast between the syenite and the overlying sedi-

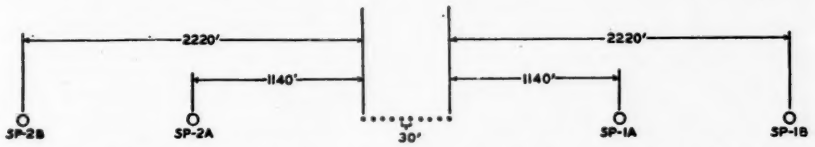


FIG. 3. Refraction spread used in the mapping of the Syenite-Paleozoic surface.

ments is sufficiently large to allow the mapping of the attitude of the syenite with the refraction seismograph. Since this surface is highly irregular the meagre core drill data available are useless for mapping the syenite, except in the immediate vicinity of the core holes. Nothing was known about the velocity contrast between the Midway and the Wilcox groups; however, this is a depositional surface, therefore nearly regular, and sufficient core hole drilling data are available to furnish a fairly reliable map of this surface. By combining the seismograph map of the syenite and the core drill map of the top of the Midway, a map of the old land surface existing at the end of Midway time can be made.

A topographic ridge cut by several streams running between Sweet Home and Bauxite offers possibilities for the presence of a buried ridge of syenite connecting the two outcrops whose top might lie above the Midway zone.

In June, 1941, a limited seismic survey of the Arkansas bauxite region was made by the National Geophysical Company for the benefit of the Reynolds Mining Corporation. The survey was conducted with a National Geophysical Company ten trace recording seismograph. Each trace was actuated by the output of one seismometer. The instrumental arrangement used is shown in Fig. 3. Using

this arrangement data were recorded in opposite directions for each spread. Since the computations were based on the first arrivals of energy from the Syenite-Paleozoic surface the distance from the shot point to the spread varied with the depth of this surface. The Syenite-Paleozoic surface is rather irregular and it is often difficult to even approximate the depth before recording. In some cases it was necessary to shoot at several distances, since the first distance used was not sufficient to give the refraction from the Syenite-Paleozoic surface as a first arrival. The longest distance used was 4000 feet. If the Syenite-Paleozoic refraction did not record as a first arrival at this distance it lay at a depth greater than 1000 feet and therefore was well below the top of the Midway. When the distances needed to be increased on any spread, new holes were drilled since the depth required was only 10–20 feet and it was faster to drill new holes than to move the instruments.

The computations were made using the usual refraction formulae for first arrival of the refracted energy. Weathering corrections were made using "up-hole times" at the shot points and short refraction profiles at the instrument spreads.

The vertical velocity for the low speed layers lying above the Syenite-Paleozoic surface was measured by "up-hole times" in several deep holes drilled throughout the area which gave a fairly constant value of 5600 feet/sec. In addition, the horizontal velocity in these beds as computed from the short refraction weathering profiles was usually close to this value.

The horizontal velocity in the syenite as determined by plotting the times of arrival against the receptor distances for shots in reverse directions, and eliminating the apparent velocities due to dip of the refracting beds, varied from 10,000 to 25,000 feet/sec. This range in velocity was observed in places where syenite was known to exist from the core hole data. Due to this large variation in the horizontal velocity of the syenite it was impossible to distinguish between the syenite and the Paleozoic rocks which have a range of horizontal velocities which overlaps the range for syenite.

Since the survey was made with the idea of obtaining a rapid reconnaissance of the area, the control was rather widely spaced except at points of unusual interest. It was possible, however, to make a map of the Syenite-Paleozoic surface and by using this map in conjunction with the map of the top of the Midway derived from the core hole data an area could be outlined, outside of which, and lying

within the area covered by the survey, it is improbable that deposits of commercial bauxite could be found. Within the favorable area it is not possible to differentiate between syenite and Paleozoic rocks, nor is it possible to predict the presence or absence of bauxite.

It is regretted that it is not possible to exhibit at this time the contoured map of the data, since this map still retains considerable commercial value to the company for which the survey was performed. It is possible, however, to obtain some idea as to the reliability of the data by referring to Table I which gives several comparisons between the seismic data and the core hole data. In general, the seismic data

TABLE I. COMPARISON OF CORE AND SEISMIC DATA

Hole No.	*Formation by Core*	*Core Depth*	*Seismic Depth*
A-8	Limestone	32	226
A-9	Limestone	75	273
C-1-A	Syenite	310	321
C-1	Syenite	225	228
C-2	Syenite	75	103
C-3	Syenite	172	173
C-4	Limestone	272	346
C-13	Syenite	227	258
D-1	Syenite	148	178
F-1	Syenite	145	149
F-2	Syenite	137	167

give greater depths than the core hole data, varying from 10 feet at core hole C-1-A to 30 feet at core hole F-2. Part of this discrepancy is due to the fact that the true first arrival of energy was not read on the records, but instead the first trough of the refraction was read and used in the computations. This was done since it was thought that this trough could be read with more accuracy than the true first arrival of the energy. If all the seismic depths are raised 20 feet to correct for this difference it is seen that an accuracy of 20 feet is indicated. It is probable that some of this variation is due to the fact that several of the old core hole locations could not be identified in the field and had to be approximated. Coring subsequent to the completion of this survey seems to indicate a slightly greater accuracy.

The authors wish to express their appreciation to Mr. O. C. Schmedeman of the Reynolds Mining Corporation for permission to publish this paper, and to Dr. George C. Branner, Arkansas State Geologist.

NOTE ON THE TRANSMISSION OF RADIO WAVES THROUGH THE EARTH*

DANIEL SILVERMAN† AND DAVID SHEFFET‡

ABSTRACT

Experiments are described and data reported on the attenuation suffered by radio signals in passing through shallow layers of the earth. Comparison is made between the measured attenuations and values computed from published formulae.

Various investigators have proposed, from time to time, methods of geophysical prospecting which involve as part of their mechanism of operation the transmission of radio waves through the earth. Each time such methods are proposed, they revive again the question of the possibility of transmission of radio waves through the earth. Although a number of studies have been reported upon in the literature,[1] the question has not been entirely closed. The reason for this, of course, lies in the fact that the properties of the earth vary over such a wide range and the effect on radio transmission of resistivity, permeability, dielectric constant, anomalous dispersion, etc., of the earth over the large range in frequencies possible, is not known to a sufficient degree to justify a direct statement in all cases.

Most authorities in the literature provide data which indicate that no great penetration of radio waves in the earth is possible. However, transmission is known to be a function of the properties of the earth and of the frequency and, in general, improves with increase in earth resistivity and with decrease in frequency. For all but the lowest frequencies the attenuation is considered to be high enough to assign a very low probability to the transmission of radio waves to any useful depth.

* Read by title at the 1942 Spring meeting, Denver, Colorado.

† Joint Exploration Laboratory of the Stanolind Oil and Gas Company and Western Geophysical Company.

‡ Naval Ordnance Laboratory, Washington, D. C.

[1] Morecroft. *Principles of Radio Communication.* Wiley & Sons, N. Y. 2nd Ed. 1927. p. 844.

Eve & Keys. *Applied Geophysics.* Cambridge University Press. 1929. pp. 136, 221.

Hund. *Phenomena in High Frequency Systems.* McGraw-Hill. 1936. p. 335.

Nettleton. *Geophysical Prospecting for Oil.* McGraw-Hill. 1940. p. 380.

Heiland. *Geophysical Exploration.* Prentice Hall. 1940. p. 811.

Feldman. *Optical Behavior of the Ground for Short Wavelengths.* Proc. I.R.E., Vol. 21, 1933. p. 293.

In contrast with the pessimistic nature of these data are experiments such as those reported[2] in which radio signals were received in caverns and mines after transmission through considerable thicknesses of rock. Unfortunately, complete data showing the resistivities, frequencies and field strength measurements on and below the surface are not given, so that the actual attenuation of the signals can only be surmised. The apparent exceptions provided by these examples have kept the question open and have undoubtedly inspired similar though unreported measurements of the transmission of radio waves through the ground to mines and caves.

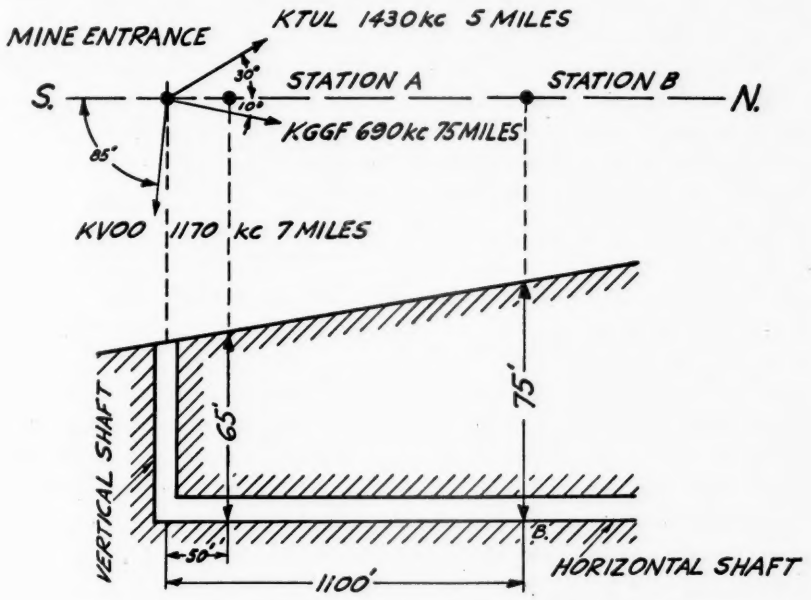


FIG. 1. Plan and elevation of test location, showing azimuths and distances of the stations observed.

An opportunity was recently presented to make some measurements of the attenuation of radio waves in the earth which are here reported in the hope that these data may throw some additional light on the subject.

The transmission measurements were made in an active coal mine near Tulsa, Oklahoma, at depths of 65 and 75 feet below the surface and at 50 and 1100 feet horizontally from a vertical entrance shaft.

[2] Eve, Keys, Lee. Proc. I.R.E., Vol. 17, No. 11, 1929, pp. 2072–74.

The location is shown in plan and elevation in Fig. 1. In the absence of a suitable transmitting source, and also to avoid the difficulties of holding field intensity constant very close to a radiating antenna, it was decided to use the transmission from regular broadcasting stations. Field strength measurements were made with an RCA type 75B field intensity meter.

To obtain significant results it was necessary to select broadcasting stations whose field intensities were constant in this region. This ruled out measurements on distant stations. However, enough variation in distance of station was provided to show that this factor was not of too great importance. It was also decided to measure stations distributed in frequency throughout the broadcast band in order to note the effect of frequency on attenuation. Selection of stations also involved choice of those ranged in different azimuth directions so that assurance could be had that the field strength measured was due to the wave coming directly from the transmitter. The stations selected to meet these requirements were KGGF, 690 kc., at a distance of 75 miles North 10° East, KVOO, 1170 kc., at a distance of 7 miles South 85° East, and KTUL, 1430 kc., at a distance of 5 miles North 30° West. The directions of these stations with respect to the measuring point are shown in Fig. 1. Measurements on the surface showed that the fields of the three stations selected were uniform in this area.

In the horizontal shaft of the mine where the measurements were made a 220 volt A.C. power line extended for a distance of 1,000 feet. There was also a 2 inch pipeline along the side of the shaft which was well grounded and extended more than 1100 feet from the vertical entrance shaft. Measurements were made in this horizontal shaft at two stations. Station A was 50 feet, and Station B, 1100 feet from the vertical entrance. Station B was therefore 100 feet beyond the end of the power line but was only 5 feet to the side of the pipeline. Station A was 65 feet and Station B 75 feet below the surface.

The data shown in Table 1 indicate the attenuation of the signals measured at stations A and B while Table 2 shows the directions from which the signals were received. At station A the signal strength was reduced by about 30:1 for each of the transmitters without any apparent relationship between attenuation and frequency. At this location the plane of the loop antenna for maximum signal was always directed North-South regardless of the station to which the receiver was tuned. In other words, the loop had to be pointed towards the vertical mine shaft for maximum signal strength.

TABLE 1. FIELD STRENGTH OF BROADCAST STATIONS

Broadcast Station	*Freq. KC*	*Field Strength On Surface* f_s	*Station A* f_a	*Station B* f_b	f_s/f_a	f_s/f_b
KGGF	690	2.1	.063	.012	33.4	175
KVOO	1170	123	4.33	.148	28.4	833
KTUL	1430	60.6	2.02	.040	30.0	1500

Since the attenuation at station A was considerably less than at station B, even though both points were roughly the same distance below the surface, and since the direction from which the signals approached the receiving instrument were the same for each signal, and exactly the direction of the shaft, the conclusion is indicated that all, or at least a major portion of the energy measured at station A arrived by way of the vertical and horizontal shafts and power line, rather than directly through the ground. The results obtained at this station can therefore be disregarded.

At station B the direction of the loop for maximum signal strength was in each case very close to the true direction of the broadcast station tuned in. The discrepancies in the cases of KGGF (10°) and KTUL (4°) fall within the limits of error due to the broad indication of the loop. In the case of KVOO the 18° difference is not easily explained on this basis, and indicates that the resultant signal received at station B is made up of two parts, one coming directly from the broadcast station through the earth, and another part arriving at B by way of the vertical and horizontal shafts. A simple vector computation indicates the direct component to be approximately 92% of the total. It can be said, therefore, that at least the major portion of the energy of the broadcast signals had to penetrate the earth in order to reach the loop antenna of the measuring set.

The attenuation of signals at this location was much greater than

TABLE 2. DIRECTIONS OF PLANE OF LOOP FOR MAXIMUM SIGNAL

Broadcast Station	*On Surface*	*Station A*	*Station B*
KGGF	N 10° E	N	N
KVOO	S 85° E	N	S 67° E
KTUL	N 30° W	N	N 34° W

Bearings are very broad, being good to about ±7 degrees.

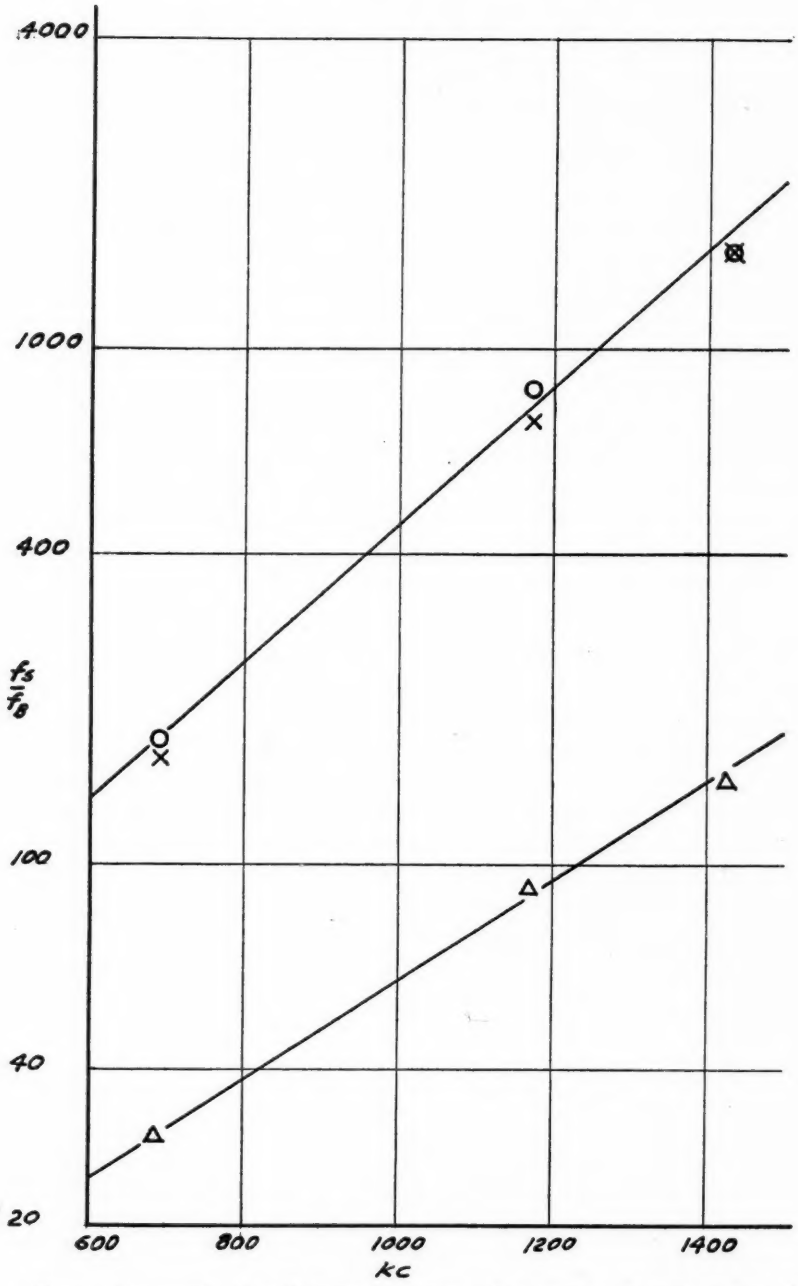


FIG. 2. Attenuation of radio frequency waves after passage through 75 feet of earth. Circles are observed values, crosses are computed on the basis of a resistivity of 5500 ohm-cm., triangles are computed on the basis of 12,000 ohm-cm.

that near the mine entrance, and also exhibited a distinct variation with frequency as shown in Table 1. These data are plotted in the upper curve of Fig. 2.

In order to compare the measured results with the theoretical attenuation of radio signals in the earth as given by A. S. Eve,[3] it was necessary to have the value of resistivity of the earth in the region of the mine. A shallow electrical resistivity depth profile, interpreted in accordance with the curves of Wetzel and McMurray,[4] gave the resistivity of the top layer as 12,000 ohm-cm and the thickness of this layer as 105 feet. The resistivity of the intermediate layer was indicated to be 1200 ohm-cm. and its thickness 35 feet.

The relationship given by Eve shows the attenuation factor to be

$$\exp\left[-\frac{2\pi fd}{c}\left\{\frac{\mu}{2}\left(\epsilon^2+\frac{4\sigma^2}{f^2}\right)^{1/2}-\epsilon\right\}^{1/2}\right]$$

where f = frequency in cycles per second
d = depth in centimeters
c = velocity of light
μ = permeability of the earth
ϵ = dielectric constant of the earth divided by 2
σ = conductivity in electrostatic units

Using this formula and the value of resistivity of 12,000 ohm-cm, the attenuations for the three frequencies observed are plotted in Fig. 2 in the lower curve. A very large discrepancy is noted between observed and computed values of attenuation. The observed attenuation for the case of KVOO, for instance, was approximately ten times as great as the computed value and similarly, for the other two stations, the attenuations observed were many times those computed on the basis of an earth resistivity of 12,000 ohm-cm. The general shape of the curve provided by the computed data was similar to that of the observed data and an attempt was made to choose a different value of resistivity such that it would make the attenuation corresponding to the frequency of 1430 KC the same in both cases. This condition was satisfied by a value of resistivity of 5500 ohm-cm. Using this value, the attenuations corresponding to the other two frequencies were com-

[3] A. S. Eve. Technical Publication No. 316, Class L, Geophysical Prospecting, No. 19. A.I.M.E. Presented at New York meeting February, 1930.

[4] Wetzel & McMurray. Three Layer Resistivity Problem. GEOPHYSICS, Vol. 2, No. 4, (Oct. 1937), pp. 321–341.

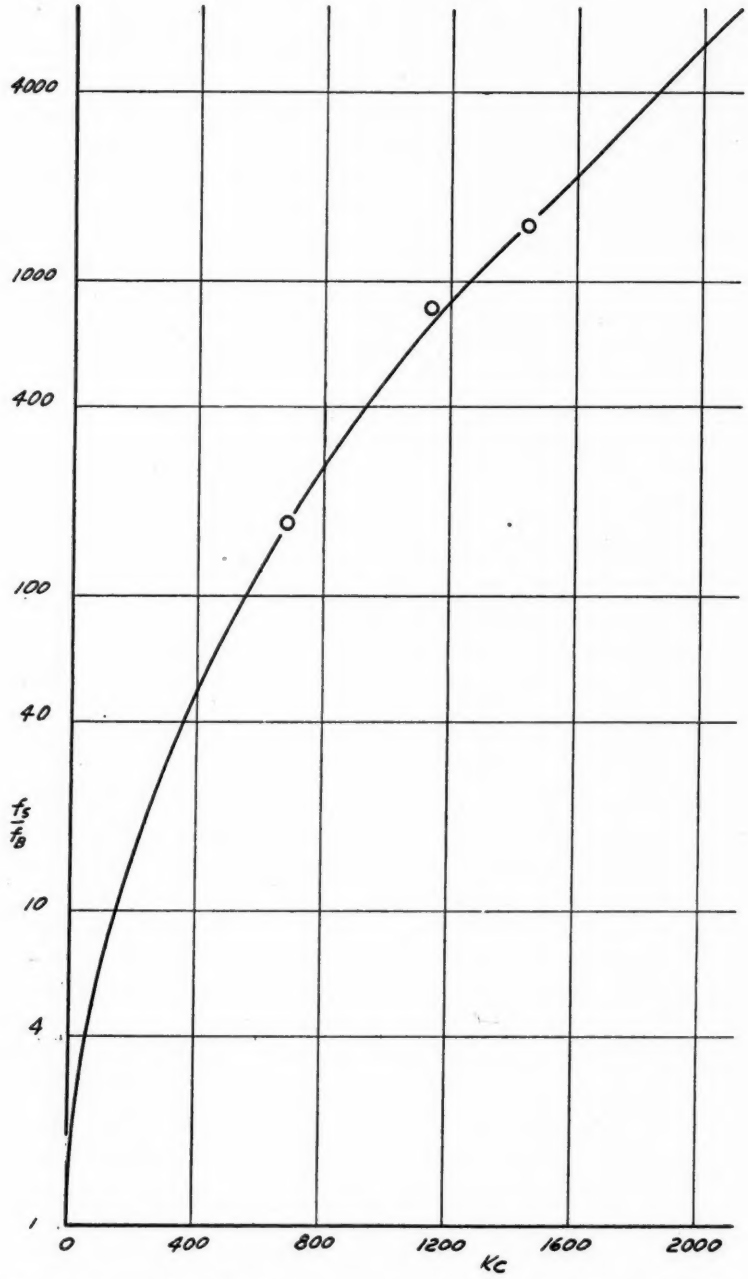


FIG. 3. Attenuation of radio frequency waves after pasasge through 75 feet of earth, extended frequency range. Circles are observed values, solid curve is computed on the basis of a resistivity of 5500 ohm-cm.

puted and are shown plotted in Fig. 2 superimposed on the observed curve. Using this value of resistivity, all three points follow closely the curve obtained by actual measurement of field strengths in the mine.

A rough substantiation of this value of resistivity is found in the data given by the Federal Communications Commission on ground conductivity in northeastern Oklahoma (F.C.C. Ground Conductivity Map of June, 1938). These data are derived from broadcast field measurements on the surface of the ground. The ground conductivity in the region of Tulsa is given as 15×10^{-14} e.m.u., which corresponds to a value of resistivity of 6600 ohm-cm. This is comparable with the value of 5500 found necessary to make a direct correspondence between observed and computed attenuations.

These experiments are admittedly incomplete since they simply give an over-all figure of loss and do not indicate what portion, if any, of the total loss occurs in the transition of the wave across the boundary plane of air and earth at the surface, and the similar plane in the tunnel, and what portion is due to the absorption in the 75 feet of earth. Assuming that the measured attenuation is truly representative of the attenuation per unit of distance in the earth, a further step has been taken using Eve's formula to extend the attenuation curve to higher and lower frequencies. This is shown in Fig. 3. It is of interest to note that the theoretical attenuation at this location at 50 KC is only 4:1 for a depth of 75 feet as compared to 1500:1 at 1400 KC. However, while the attenuation is very considerably reduced for low frequencies, the practical difficulty of radiating energy is almost insurmountable, requiring for a quarter wave length antenna at 50 KC a wire of approximately 1500 meters in length.

This report is admittedly incomplete, in many respects, and particularly as to the effect on attenuation of the proximity of the transmitter, and the directivity of the antenna system. This was, of course, impossible to determine under the experimental conditions.

Appreciation is expressed to Mr. L. Watt Stinson and to the management of station KVOO for the loan of the field strength meter used in making these observations, and to the officers of the Stanolind Oil and Gas and Western Geophysical Companies for permission to publish this note.

THE IMPEDANCE OF A GROUNDED WIRE*

ALFRED WOLF†

ABSTRACT

The impedance of an insulated wire stretched along the surface of the earth, regarded as a homogeneous conductor, is a function of frequency and of the conducitivity of the earth. Formulas are given for the inductance and the resistance of such a wire which are applicable under conditions met with in geophysical prospecting.

In connection with some problems of electrical prospecting, it is sometimes required to calculate the inductance of a long insulated wire stretched along the surface of the earth and grounded at both ends. The earth, which is regarded as a semi-infinite homogeneous conductor, forms the return part of the electric circuit and causes the impedance to vary with frequency. This is the case because the current penetration into a conductor is a function of frequency, and determines both the inductance and the a.c. component of the resistance of the grounded wire. The d.c. component of resistance is a function of the size of the wire and of the electrodes used for grounding, and will not be considered further.

In the following, it will be assumed that the length of the wire is great compared to its diameter and to the dimensions of the grounding electrodes. Further, the frequency is taken to be low enough, so that the skin effect in the wire itself is negligible. These conditions are valid for a wide range of circumstances met with in the practical application to gephysical prospecting.

Carson[1] has solved a problem similar to the above on the assumption that the length of the wire is great compared to the wave length; his results can be employed in calculations dealing with long telephone lines. The fundamental assumption made in the following is that the current along the grounded wire is constant. The calculation is based on formulas given by Foster[2] for the mutual impedance of grounded wires. The earth is regarded as a homegeneous conductor of negligible magnetic susceptibility.

Let a unit current of frequency f be passed through the wire. The integral of the electric field along a straight line parallel to the wire,

* Read by title at the Denver meeting, April, 1942.

† Geophysical Research Corporation, Tulsa, Oklahoma.

[1] J. R. Carson: Bell System Technical Journal 5, 1926, p. 539.

[2] R. M. Foster: Bell System Technical Journal 10, 1931, p. 409.

at a distance x from it, and of the same length as the wire, is, according to Foster, given by

$$M(x) = F(x)/2\pi\lambda \tag{1}$$

where

$$F(x) = \int_{-a}^{a} dv \int_{-a}^{a} du \frac{1 - (1 + \gamma r)e^{-\gamma r}}{r^3} \tag{2}$$

with

$$r = \sqrt{x^2 + (u - v)^2}$$
$$\gamma = \sqrt{4\pi j\omega\lambda}$$
$$\omega = 2\pi f$$
$$j = \sqrt{-1}$$
$$2a = l = \text{length of wire}$$
$$\lambda = \text{conductivity of the earth in e.m.u.*}$$

Since the distribution of current in the wire is uniform, the a.c. component of impedance will be obtained approximately by averaging $M(x)$ over the cross-section of the wire. This step is necessary, as in all cases of self-inductance calculation, because $M(x)$ becomes logarithmically infinite as x approaches zero. The total impedance of of the circuit is

$$Z = R + \overline{F(x)}/2\pi\lambda \tag{3}$$

where R is the d.c. resistance in e.m.u. The resistance of the wire itself is included in R.

Since the radius of the wire is small compared to its length, $F(x)$ has to be determined only for small values of x.

If the variables

$$\xi = \frac{1}{\sqrt{2}}(u - v)$$
$$\eta = \frac{1}{\sqrt{2}}(u + v) \tag{4}$$

* All quantities are expressed in absolute electro-magnetic units. 1 Ohm = 10^9 e.m.u., 1 Henry = 10^9 e.m.u.

are introduced, the integrand in (2) becomes independent of η. The integration with respect to η introduces the factor.

$$2\sqrt{2}\,a\left[1-\frac{|\xi|}{\sqrt{2}\,a}\right]$$

and after substituting

$$\sqrt{2}\,\xi = t$$

$$F(x)/2l = \int_0^l dt\,\frac{1-(1+\gamma\sqrt{x^2+t^2})\exp\left[-\gamma\sqrt{x^2+t^2}\right]}{(x^2+t^2)^{3/2}} - \frac{1}{l}\int_0^l t\,dt\,\frac{1-(1+\gamma\sqrt{x^2+t^2})\exp\left[-\gamma\sqrt{x^2+t^2}\right]}{(x^2+t^2)^{3/2}}. \tag{5}$$

From (5) it follows easily

$$F(x)/2l = \frac{l}{x^2\sqrt{x^2+l^2}}\left(1-\exp\left[-\gamma\sqrt{x^2+l^2}\right]\right) - \frac{\gamma}{x^2}\int_0^l \exp\left[-\gamma\sqrt{x^2+l^2}\right]du \tag{6}$$

$$-\frac{1}{lx}\left(1-e^{-\gamma x}\right)+\frac{1}{l\sqrt{l^2+x^2}}\left(1-\exp\left[-\gamma\sqrt{x^2+l^2}\right]\right).$$

Since only terms of the lowest order in x are to be preserved this can be written

$$F(x)/2l = \frac{1-e^{-\gamma l}}{x^2} - \frac{\gamma}{x^2}\int_0^l du\cdot\exp\left[-\gamma\sqrt{l^2+u^2}\right] - \frac{\gamma}{l}+\frac{1-e^{-\gamma l}}{2l^2}+\frac{\gamma e^{-\gamma l}}{2l}. \tag{7}$$

Now, since

$$\int_0^l du\cdot\exp\left[-\gamma\sqrt{u^2+x^2}\right] = \int_0^\infty - \int_l^\infty = xK_1(\gamma x) - \int_l^\infty,$$

and since

$$xK_1(\gamma x) = \frac{\gamma x^2}{2}\log\frac{\gamma x}{2}+\frac{1}{\gamma}+ \textit{terms of higher order in } x$$

it follows that

$$F(x)/2l = \frac{\gamma^2}{2}\left[\log\frac{2}{\gamma x} - \int_l^\infty \frac{du}{u}e^{-\gamma u}\right] + \frac{1}{2l^2}\left[1 - e^{-\gamma l} + \gamma l e^{-\gamma l} - 2\gamma l\right]. \tag{8}$$

Averaging $\log 1/x$ over the cross-section of the wire gives

$$\overline{\log\frac{1}{x}} = \log\frac{1}{b} + \frac{1}{4} \tag{9}$$

where b is the radius of the wire.

Combining (3), (8), (9) it follows that

$$Z = R + j\omega\cdot 2l\left[\log\frac{2}{\gamma b} + \frac{1}{4} - \int_{\gamma l}^\infty \frac{du}{u}e^{-u} + \frac{1}{\gamma^2 l^2}(1 - e^{-\gamma l} + \gamma l e^{-\gamma l} - 2\gamma l\right]. \tag{10}$$

The evaluation of the complex logarithmic integral in (10) would involve considerable labor since tables are not available. Fortunately, the formula can be simplified both for low and for high frequencies.

When $\gamma l \ll 1$

$$\int_l^\infty \frac{du}{u}e^{-\gamma u} = -\log 1.781\gamma l.*$$

It follows that, for low frequencies, ($\gamma l \ll 1$), when the current penetration is greater than the length of the wire

$$Z = R + j\omega 2l\left[\log\frac{3.562l}{b} - 1.25\right] \tag{11}$$

and the low frequency inductance is

$$2l\left[\log\frac{l}{b} + .02\right].$$

When the current penetration is smaller than the length of the wire, so that $\gamma l \gg 1$, but still $\gamma b \ll 1$, the exponential terms in (10) can be neglected and

* *Cf.*, Jahnke-Emde: *Tables of Functions*, 2nd ed., p. 79.

$$Z = R + \omega \frac{\pi l}{4} + j\omega 2l\left[\log \frac{1}{b\sqrt{\pi\omega\lambda}} + \frac{1}{4}\right]. \tag{12}$$

The expression

$$2l\left[\log \frac{1}{b\sqrt{\pi\omega\lambda}} + \frac{1}{4}\right] \tag{13}$$

for the high frequency inductance of the circuit decreases slowly as the frequency increases.

A certain amount of resistance is introduced into the circuit because of the concentration of current near the surface of the ground. This a.c. component of resistance is given by the second term on the right hand side of (12)

$$\frac{\pi}{4}\omega l. \tag{14}$$

As an illustration, the following problem may be considered. A No. 18 copper wire conductor ($b = 0.051$ cm) a mile long ($l = 1.609 \times 10^5$ cm) is stretched along the surface of the earth which is assumed to have a resistivity of 1000 *ohm-cm* ($\lambda = 10^{-12}$ *e.m.u.*). It is desired to calculate the resistance which is needed in the circuit in order that its time constant be 0.0001 *sec.* The inductance will be calculated for a frequency of 2500 *cps*, since that makes the duration of a quarter cycle equal to the time constant. The value of $|\gamma l|$ at this frequency is 71.4, and, hence, the inductance is obtained from (13), and the high frequency ground resistance from (14). An easy calculation shows the inductance to be 0.00374 *henrys* and the a.c. component of ground resistance, neglecting the resistance at the grounding electrodes, is 2.0 *ohms*. A time constant of 0.0001 *sec.* requires a total circuit resistance of 37.4 *ohms* and, consequently, the value of the d.c. resistance R should be 35.4 *ohms*. This happens to be very nearly the value of the resistance of the copper conductor itself which is 34.4 *ohms* at 25° *C*.

DISCUSSIONS AND COMMUNICATIONS

To the Editor:

In his paper in the April and July 1942 issues of GEOPHYSICS, Dr. Sharpe gives a very enlightening analytic solution to the problem of the wave motion generated in an elastic medium by application of a pressure of arbitrary form to the interior surface of a spherical cavity. It is very encouraging to find that deductions regarding the relation of the amplitude and frequency of the generated wave to the physical characteristics of the medium agree so well with empirical operation. A thorough understanding of the explosion process and its accompanying wave phenomena is a prerequisite to the final refinement of the seismograph as a tool of Exploration Geophysics. It is to be hoped that Dr. Sharpe and his colleagues, as well as others, will continue the combined analytic and experimental attack.

In connection with this discussion of Dr. Sharpe's paper, I wish to call attention to A.I.M.M.E. Technical Paper 1268, in the Petroleum Division Transactions for 1941, by Evinger and Muskat, on "Some Theoretical Considerations on the Problem of Well Shooting," that is, on the problem of shooting oil wells for the purpose of increasing production. To a considerable extent these papers are complementary. Dr. Sharpe is principally concerned with the wave motion outside the sphere or zone of fracture, whereas, Dr. Muskat and Mr. Evinger are concerned with the stresses in the medium and with the interior of the sphere or zone of fracture. Geophysicists, by virtue of their training and instrumental facilities for measuring displacement, velocity, acceleration, and stress in a medium, and density, seismic wave velocity and elastic parameters of rocks, are eminently fitted to improve our knowledge of this important production problem.

GEORGE B. LAMB

Houston, Texas,
August 26, 1942.

REVIEWS

A Magnetic Survey of Central South Dakota. Geophysics by W. H. Jordan. Geology by E. P. Rothrock. South Dakota Geological Survey Report of Investigations No. 37 (Vermillion, Nov., 1940). 35 pp., 8 illus., including magnetic map of area.

Magnetometer Surveys During 1941, by Edward L. Tullis. South Dakota Geological Survey. Report of Investigations No. 42 (Vermillion, March, 1942). 40 pp., 13 illus., including magnetic map of area.

These are the two latest reports on the program of magnetic observation which has been undertaken by the South Dakota State Geological Survey. According to R. I. No. 37 the plan is to make a magnetic survey of the entire state. The purpose of this program according to R. I. No. 37 is "first to obtain information for the people of the state, and second to encourage further activity on the part of the oil companies." To accomplish this purpose they are making a regional magnetic (vertical component) map of the state. Magnetic stations are located approximately six miles apart. Most of the work to date covers a large area located in the central part of the state and extending from the southern to the northern boundary. R. I. No. 37 presents the vertical magnetic data at 118 stations, covering approximately 10,000 square miles. R. I.

No. 42 gives the same data for 237 additional stations, covering an area of approximately 6850 square miles.

Both reports discuss very briefly the theory and field technique of magnetic surveying as well as the construction of the magnetometer. Both reports also discuss briefly the theory of interpretation of magnetic data, and offer some interpretation of the data obtained by these two surveys.

All station values have been corrected for difference in latitude and longitude. The exact corrections used are given. A map showing the amount of the error of misclosure is included in each report. The map of misclosure, the discussion of errors, and the discussion of the field methods which were used give one a good idea of the accuracy of the work.

A contoured magnetic map is included in each report. The contour interval used is 100 gammas. The station locations are shown on the map, but not the values at the individual stations. The individual station locations and values are tabulated so that the data may be transferred to any other map for additional study. Any geologist or geophysicist interested in South Dakota will welcome the activity of the State Geological Survey in preparing these reports.

GARVIN L. TAYLOR

Seismology, by Perry Byerly. 256 pp. Prentice-Hall, New York, 1942.

The book is divided into two parts, the first of which appears to be lecture notes for a popular course in seismology. The various theories and speculations as to the immediate and underlying causes of earthquakes are set forth and the effects of earthquakes are described with numerous photographic illustrations. Brief descriptions of great earthquakes of history are given, the earliest one described being the St. Lawrence Valley earthquake of 1663. In a chapter on the distribution of earthquakes, the author assigns a seismicity of 10 to the San Francisco Bay Area and 3.6 to the Los Angeles Area and one wonders how long these figures will remain unchallenged.

Part II of the book covers instrumental and wave theory, instrumental observations, and interpretations. Seismograph theory is developed using operational methods. Elastic wave theory is set forth in almost outline form. Seismic prospectors should find the chapters on "Paths of Waves and Travel Times" and "Location of Epicenters" of interest. In reading them, they should bear in mind that the seismologist ordinarily works without a time break, with no exact knowledge of the location of the "shot point," no weathering information, no well velocity surveys, and no correlation spreads. However, the simplicity of having to deal with only one recognized subsurface reflecting interface, may seem adequate compensation.

The author has achieved his desire for brevity and provides references at the end of each chapter for those interested in detail.

KARL DYK

PATENTS*

ELECTRICAL PROSPECTING

U.S. No. 2,284,990. M. Schlumberger. Iss. 6/2/42. App. 7/5/39.

Method and Apparatus for Electrical Prospecting. A method of electrical prospecting making use of telluric earth currents in which the earth potentials or their derivatives are recorded by frequency selective devices.

U.S. No. 2,288,310. T. Zuschlag. Iss. 6/30/42. App. 4/23/38. Assign. Lundberg Exploration S. A.

Apparatus for Geoelectric and Seismic Investigations. A method of comparing steady state a-c voltages obtained either in a-c electrical prospecting or continuous wave seismic prospecting by using two amplifiers whose outputs are connected in a bridge circuit and balanced.

GEOCHEMICAL PROSPECTING

U.S. No. 2,284,147. H. N. Herrick. Iss. 5/26/42. App. 1/28/39. Assign. Standard Oil Co.

Method and Apparatus for Soil Gas Analysis. A method of collecting soil gas samples by sealing a cavity in the soil, permitting atmospheric breathing, and absorbing hydrocarbon gas from the air passing in and out of the cavity during the breathing process.

U.S. No. 2,287,059. R. N. Platts, F. B. Slichter, E. L. O'Donnell, and P. T. Bennett. Iss. 6/23/42. App. 5/25/40.

Apparatus for Obtaining Soil Samples. A sample or core taking machine which forces a hollow cutter into the earth by hydraulic pressure.

U.S. No. 2,287,101. L. Horvitz. Iss. 6/23/42. App. 1/8/38. Assign. E. E. Rosaire.

Means and Method of Analysis. A method of analyzing soil gas for minute traces of hydrocarbons in which the gas is circulated repeatedly around a closed loop having a refrigerating and a combustion zone.

SEISMOGRAPH PROSPECTING

U.S. No. 2,285,610. O. S. Petty. Iss. 6/9/42. App. 8/1/40.

Method and Apparatus for Seismic Surveying. A seismograph amplifier which differentiates the initial wave form.

U.S. No. 2,286,106. O. F. Ritzmann. Iss. 6/9/42. App. 2/9/39. Assign. Gulf Research & Development Co.

Apparatus for and Method of Receiving and Recording Vibrations. A seismograph amplifier having an automatic characteristic control which is effected by the first arrivals but which is subsequently cut off and thereafter acts as a function of time only.

U.S. No. 2,286,170. C. A. Heiland. Iss. 6/9/42. App. 7/26/37. Assign. Heiland Research Corp.

* Abstracts by O. F. Ritzmann, Gulf Research & Development Co.

Selector System for Amplifiers. A system of controlling the amplification of seismograph amplifiers according to any predetermined function of time, control being accomplished by means of a time sequence of shutters interposed between a lamp and a photocell which effects the amplification.

U.S. No. 2,286,386. D. Silverman. Iss. 6/16/42. App. 12/7/39. Assign. Stanolind Oil and Gas Co.

Seismometer. A suspended magnet type of dynamic geophone having two elements, the coil of each being rigidly attached to the magnet of the other and the coils electrically connected so as to eliminate response to rotational motion.

U.S. No. 2,286,567. J. O. Parr, Jr. Iss. 6/16/42. App. 9/12/40. Assign. Olive S. Petty.

Seismic Surveying. A vacuum tube circuit for combining the outputs of a number of geophones so that response is blocked unless all geophones are delivering voltage of the same sign.

U.S. No. 2,286,897. P. J. Costa and G. E. Holback. Iss. 6/16/42. App. 12/20/38.

Vibration Pickup. A dynamic type vibrometer having a suspended magnet and stops connected so as to short circuit the coil if the vibrating amplitude becomes excessive.

U.S. No. 2,288,838. E. W. Pike and A. W. Vance. Iss. 7/7/42. App. 2/29/40. Assign. Radio Corp. of America.

Vibration Pickup Device. A displacement type vibrometer in which the vibration changes either the capacity or the inductance in a resonant circuit connected to a source of constant frequency a-c slightly off resonance.

WELL LOGGING AND SURVEYING

U.S. No. 2,284,345. C. H. Schlesman. Iss. 5/26/42. App. 10/21/41. Assign. Socony-Vacuum Oil Co.

Method and Apparatus for Geophysical Prospecting. A gamma ray well logging instrument using a number of detectors which are connected in sequence to the recording mechanism, the sequence rate being related to the rate of movement of the instrument so as to give improved resolving power.

U.S. No. 2,285,809. R. F. Davis. Iss. 6/9/42. App. 4/4/40. Assign. Well Surveys, Inc.

Well Surveying Method and Apparatus. A method of transmitting information obtained by a well logging device to the surface by means of mechanical vibrations sent up through the supporting cable.

U.S. No. 2,285,840. S. A. Scherbatskoy. Iss. 6/9/42. App. 8/4/39. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A gamma ray well logging device using two ionization chambers, one of which responds to all radiations and one shielded to respond only to hard radiations, and recording the difference in their ionization currents in order to eliminate the effect of sources close to the device.

U.S. No. 2,288,278. L. G. Howell. Iss. 6/30/42. App. 6/23/41. Assign. Standard Oil Development Co.

Gamma Ray Well Logging. A method of obtaining gamma ray logs from an instrument having a number of counters but using only a single cable by filtering the pulses from each counter before impressing them on the cable and again filtering at the surface to identify the pulses from the respective counters.

U.S. No. 2,288,876. J. C. Arnold. Iss. 7/7/42. App. 1/21/41. Assign. Lane-Wells Co.

Magnetic Logging. A magnetic well logging device in which an inductor coil is rotated simultaneously about a horizontal and a vertical axis while traversing the hole and recording the instantaneous form of the emf generated.

U.S. No. 2,288,884. M. C. Bowsky. Iss. 7/7/42. App. 12/11/39. Assign. Lane-Wells Co.

Electrical Logging in Oil-Filled Wells. An a-c electrical well logging method in which the electrodes make contact with the walls of the hole and using a constant current a-c source, the pick up circuit being inductively coupled to the exciting circuit so as to eliminate contact resistances.

U.S. No. 2,288,973. J. Neufeld and E. H. Cooley. Iss. 7/7/42. App. 12/15/39. Assign. Well Surveys, Inc.

Well Surveying Method and Apparatus. A method of determining dip of underground strata traversed by a well by observing the asymmetry of the current field when one terminal of a battery is connected to an electrode in the well and the other terminal is connected through resistors to two surface electrodes diametrically opposite and equidistant from the well.

U.S. No. 2,289,926. J. Neufeld. Iss. 7/14/42. App. 3/18/40. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A method of radioactivity well logging in which a record is made of the natural radioactivity and another record of the combined natural plus induced radioactivity, and by subtraction arriving at a record of the induced radioactivity alone.

U.S. No. 2,290,075. M. Schlumberger. Iss. 7/14/42. App. 4/3/39. Assign. Schlumberger Well Surveying Corp.

Thermal Process and Device for Surveying the Beds Traversed by Drill Holes. A method of obtaining a thermal property log of a well by simultaneously heating an extended portion of the well fluid by a current carrying resistance wire and making a temperature survey before and after the heating.

MISCELLANEOUS

U.S. No. 2,284,654. B. M. Harrison. Iss. 6/2/42. App. 10/20/38. Assign. Submarine Signal Co.

Distance and Depth Measuring Device. An echo-sounding device in which corrections for water temperature and salinity are automatically made by the method of having the depth indicator driven through a differential gearing by two adjustable speed electric motors.

U.S. No. 2,286,673. L. A. Douglas. Iss. 6/16/42. App. 6/10/41.

Means for Extracting the Core Content of Subterranean Strata. A side wall sampling device having a mechanically operated plunger which is forced into the side wall and a vacuum chamber which takes up gas or liquid from the side wall cores.

U.S. No. 2,287,819. P. B. Nichols. Iss. 6/30/42. App. 5/21/38. Assign. One-half to Cities Service Oil Co.

Device for Recording Drilling Operations. A rate-of-drilling recorder which records time, depth, speed of penetration, vertical chatter of drill pipe and other drilling operations.

U.S. No. 2,288,210. M. Schlumberger. Iss. 6/30/42. App. 5/3/39.

Core Taking Projectile. An easily withdrawable side wall coring projectile having a flange or collar which makes a hole larger than the main part of the projectile and which is loosened from the projectile during impact.

U.S. No. 2,288,942. R. L. Doan. Iss. 7/7/42. App. 6/11/40. Assign. Phillips Petroleum Co.

Fluoroscope. A portable apparatus for detecting crude oil in drilling mud in which the mud is continuously circulated under a source giving only ultraviolet light and the fluorescence is observed through an eyepiece shielded from direct rays of the source.

U.S. No. 2,289,961. J. E. Hancock. Iss. 7/14/42. App. 5/6/39. Assign. General Electric Co.

Vibration Generator. A dynamic type vibrator for vibration testing of materials including a smaller dynamic type pickup device for determining the actual motion developed.

U.S. No. 2,289,962. J. E. Hancock. Iss. 7/14/42. App. 5/6/39 and 11/6/41. Assign. General Electric Co.

Vibraton Device. A dynamic type vibrator having a locking device to prevent straining the moving system when specimens are being mounted on it.

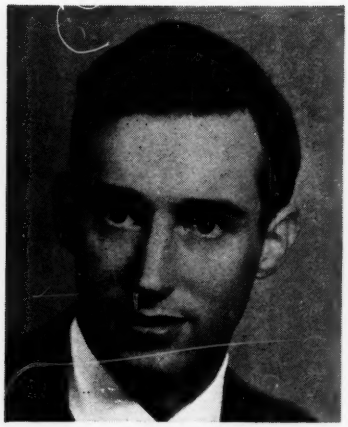
CONTRIBUTORS

D. C. SKEELS received a B.A. degree from the University of Montana in 1930, with a major in physics and mathematics, after which he spent three years as a Rhodes Scholar at Oxford, where he studied geology. He then studied for the Ph.D. degree in geology at Princeton, receiving his degree in 1936. Dr. Skeels has been engaged in geophysical work since 1936, in Tulsa for the Carter Oil Company, and in New York City for the Standard Oil Company of New Jersey. He is a member of Sigma Xi, the American Association of Petroleum Geologists, the American Geophysical Union, and the Society of Exploration Geophysicists.

D. C. SKEELS

BIRD G. SWAN

BIRD G. SWAN received his B.S. degree in Geological Engineering from the University of Oklahoma in 1932, after having spent the two previous years with Continental Oil Company in torsion balance and seismograph field work. Since 1932 he has been associated with Continental Oil Company as seismograph computer, party chief, and since 1937 in interpretative and administrative work in the Ponca City office. Mr. Swan is a member of the Society of Exploration Geophysicists.



MILTON B. DOBRIN

MILTON B. DOBRIN was graduated from the Massachusetts Institute of Technology in 1936 and subsequently attended Columbia University and the University of Pittsburgh, receiving his M.S. at the latter institution in 1941. In 1937 he became connected with the Geophysics Division of the Gulf Research and Development Company for whom he was engaged in seismic interpretation both at the company's Pittsburgh headquarters and in the field. In June, 1942, he joined the staff of the Naval Ordnance Laboratory, Washington, D. C., as a contract physicist. He is a member of the American Physical Society, the American Geophysical Union and the Society of Exploration Geophysicists.

LORENZ SHOCK attended the University of Oklahoma, where he received an A.B. degree in 1937. After a summer with the Western Geophysical Company he returned to the University as a research scholar, receiving his M.S. degree in 1938. Mr. Shock has been employed by the National Geophysical Company since 1938, with the exception of one year spent at the University of Oklahoma as a graduate student and part time instructor in physics. He is a member of Phi Beta Kappa and an associate member of Sigma Xi.

LORENZ SHOCK

E. D. ALCOCK

E. D. ALCOCK received an A.B. degree in mathematics from U.C.L.A. in 1930, after which he worked for the Bell Telephone Laboratories for two years as a research engineer. He then returned to take his Ph.D. degree in physics at the California Institute of Technology, in 1935. After receiving his Ph.D., Dr. Alcock accepted employment in the geophysical industry, first with the Shell Petroleum Corporation, for whom he worked three years as a seismologist, and then with National Geophysical Company, with whom he is now employed.

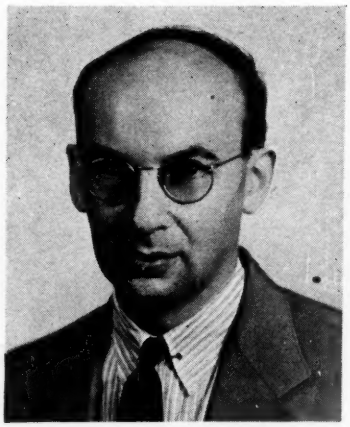
DANIEL SILVERMAN

DANIEL SILVERMAN received his B.S. degree in 1927 from the University of California. He attended the Massachusetts Institute of Technology from 1928–30 as the Heller Travelling Fellow from the University of California. There he received his M.S. degree in 1929 and Sc.D. in 1930. He was employed as research engineer by the Westinghouse Research Laboratory from 1930 to 1934, and by the Arma Corporation of Brooklyn, N. Y., from 1934 to 1936, where he worked on the development of navigation and fire control instruments for the U. S. Navy. He spent the year 1936–37 as Asst. Professor of Mechanical Engineering at the University of California, and then became associated with the Joint Exploration Laboratory of the Stanolind Oil and Gas Company and Western Geophysical Company in 1937 as physicist in charge of design and construction, and since 1940, as laboratory supervisor in charge of all research and development activities.

Dr. Silverman is a member of the American Association of Petroleum Geologists, the American Institute of Mining and Metallurgical Engineers, the Society of Exploration Geophysicists, the Seismological Society of America, the American Geophysical Union, the Acoustical Society of America, and the Institute of Radio Engineers.

DAVID SHEFFET

DAVID SHEFFET attended the California Institute of Technology, where he received a B.S. degree in electrical engineering in 1930 and an M.S. degree in 1931, and served as a laboratory instructor and took additional graduate work in 1932. Mr. Sheffet did electronic development work in 1933 for the Western Electronics Company, well-logging research in 1934 for the Elliott Core Drilling Company, and then joined the staff of the Joint Exploration Laboratory of the Stanolind Oil and Gas Company and the Western Geophysical Company, where he has specialized in instrumental developments. Since 1941 Mr. Sheffet has been on leave from his firm as a contract employee of the Naval Ordnance Laboratory. He is a member of the Society of Exploration Geophysicists.



ALFRED WOLF

ALFRED WOLF took his B.S. and M.S. in physics at M.I.T. in 1922 and 1923, and after four years of work in geophysics at the Mellon Institute on behalf of the Gulf Oil Corporation and the Geophysical Research Corporation, went to Leipzig where he received his Ph.D. in 1931. Dr. Wolf has been associated with the Geophysical Research Corporation since 1935, engaging principally in theoretical investigations of exploration problems. He is a member of the American Association for the Advancement of Science, and a Fellow of the American Physical Society.

OTTO F. RITZMANN, who prepares the patent abstracts which are a regular feature of GEOPHYSICS, received his B.S. degree in electrochemical engineering from Pennsylvania State College in 1922, and his M.S. degree in physics in 1924. He continued his graduate work in physics at the California Institute of Technology. Mr. Ritzmann taught college physics at the Pennsylvania State College, California Institute of Technology, Michigan College of Mines, and Lehigh University and in 1929 joined the staff of the Gulf Research and Development Co. He is a member of Phi Kappa Phi, Sigma Xi, American Association for the Advancement of Science, American Physical Society, American Geophysical Union, Society of Exploration Geophysicists, and the Physical Society of Pittsburgh.

OTTO F. RITZMANN

ARNOLD J. F. SIEGERT. A biography and photograph will be found in GEOPHYSICS, Vol. VII, No. 1, (January 1942).

THE SOCIETY ROUND TABLE

ANNOUNCEMENTS

STUDENT COMPETITION

At a meeting of the Executive Committee held in Houston on August 26, 1942, it was decided that steps be taken to encourage the submittal of papers from graduate and undergraduate members of universities. To achieve this it was decided to make use of the authority granted to the Executive Committee by the amendment to the by-laws adopted at the annual meeting in Denver, under which suitable prizes may be awarded for the best papers. A notice announcing these prizes will be circulated to all universities where courses in geophysics are customarily given. The proposed form of this notice is as follows:

"The Society of Exploration Geophysicists desires to stimulate study of geophysical problems by encouraging the publication by undergraduate and graduate students of papers dealing with geophysics. Accordingly, the Society is willing to consider such papers for publication in its Journal GEOPHYSICS. In particular it is hoped that theses dealing with geophysical problems which have been accepted from candidates for degrees will be submitted.

The Editor, and such committee as he may appoint for the purpose, will referee all papers submitted and in the event an outstanding paper is received and published which in the opinion of the Editor merits special recognition, the author may, at the discretion of the Executive Committee, be awarded free membership in the Society for a period of three years in the class of membership for which he is eligible (i.e., Student, Associate or Active).

Manuscripts should be submitted to the Editor, Joseph A. Sharpe, P. O. Box 591, Tulsa, Oklahoma. These should be an original typewritten copy, either double or triple spaced, with wide margins. Manuscripts and illustrations of papers not accepted for publication will be returned to the authors; manuscripts and illustrations of published papers will be destroyed immediately after publication unless the author requests their return."

FEDERAL EXPLOSIVES ACT

Section 18 of the Federal Explosives Act of December 26, 1941, authorizes the Director of the Bureau of Mines to issue rules and regulations to effectuate the purposes of this Act. The Bureau has issued regulations and appointed explosives investigators to supervise the carrying out of such regulations. The supervising engineer for District G, embracing most of the territory in the southwestern states where seismograph operations are being carried out, is Mr. G. M. Kintz whose office is 544 Federal Building, Dallas, Texas. During the Annual Meeting of the Society at Denver, a conference with Mr. Kintz was arranged for the purpose of discussing regulations to be promulgated by the Bureau of Mines. A committee of the Society comprising Messrs. G. W. Carr, T. I. Harkins, F. F. Reynolds and F. Goldstone was appointed by the President to make recommendations to the Bureau of Mines. This committee drafted such recommendations which were in due course forwarded to Washington. A further meeting was held in Dallas at which Mr. Kintz, his inspectors, and representatives of geophysical companies were present. At this time further discussion was had concerning the specifications for field storage magazines and other related matters.

Growing out of these various conferences and others held by the Bureau of Mines with different branches of industry using explosives, a brochure was issued dated July 15, 1942, under the title "Instructions for Storing, Handling and Transporting Explosives." This can be obtained from the Department of Interior, Bureau of Mines, Explosives Control Division, at Washington, D. C. These instructions do not lay down inflexible rules on all matters, much being left to the judgment of explosives investigators and other inspectors of the Bureau of Mines in the field; accordingly, the following letter from Mr. Kintz to Mr. Goldstone under date of September 14, 1942, will be of interest.

Mr. F. Goldstone, President
Society of Exploration Geophysicists
P. O. Box 2099
Houston, Texas

Dear Mr. Goldstone:

After the meeting here in Dallas with the representatives of the various geophysical companies, their suggestions were submitted to our Washington office, and I am glad to say that the Washington office agreed with what was decided on at that meeting, namely:

1. Present geophysical magazines of No. 10 or 14 gauge steel, properly ventilated, when lined with 2 inches of red oak or equivalent material, shall be approved. Extra precautions that may be taken are: removal of wheels to prevent theft of magazines; a second lock on the door as required; a mortice-type lock if obtainable, or when padlocks are used, they should be covered with hoods; or the forming of a barricade around the magazine by use of bags filled with sand or dirt.

2. When the detonator magazines are constructed as provided in Section 2B(c), of the Instructions, or as described in your letter, and are securely fastened to a piece of drill casing 10 to 15 feet in length, which is inserted in a vertical hole, they may be approved as satisfactory. Additional precautions may include addition of a second lock as in (1) and the barricading of the box by use of bags filled with sand or dirt.

3. In regard to shooting trucks: two magazines will be allowed on the same truck, one to be used for explosives and the other fo. letonators, when properly constructed and lined. They shall be kept locked at all times excepting when in use. A partition placed in one magazine to make separate compartments will not be acceptable. Otherwise, trucks shall conform to all the other regulations for transportation as provided in the Instructions.

4. Where companies do not at the present time possess portable metal magazines, they may submit to this office, or any district Bureau office, specifications of the construction details of the type of magazine that they wish to build, and the office will advise whether or not it will meet the necessary specifications. Thought should be given to constructing the magazine along the following lines:

5. A portable magazine constructed of 2 inches of tongue and grooved oak lumber, 2 inches of packed cotton fibre, and 1 inch of matched flooring on the outside, will be acceptable for this type of work. Further recommendations may include the covering of the magazine with No. 26 gauge iron, if obtainable. Under certain conditions, if the iron cannot be obtained, asbestos or similar fire-resisting material might be accepted

as covering for this wood. In all cases it will be necessary that the magazines be inspected by a Bureau of Mines representative before it can be considered as approved.

I wish to express the appreciation of the Bureau and myself for the cooperation you have given us in this work.

Very truly yours,
(Signed) G. M. KINTZ
Supervising Engineer
District G

APPOINTMENT OF REGIONAL EDITORS

Section V-B-4 of the Constitution and By-Laws of the Society provides that the Editor may appoint associate, regional, and special editors to assist him in performing his editorial duties. The Editor wishes to announce the appointment of the following Regional Editors:

DR. L. L. NETTLETON, Gulf Research and Development Company, Pittsburgh, Pennsylvania, for the EASTERN AREA;

DR. W. M. RUST, JR., Humble Oil and Refining Company, Houston, Texas, for the GULF COAST AREA;

PROF. DART WANTLAND, Colorado School of Mines, Golden, Colorado, for the ROCKY MOUNTAIN AREA; and

DR. H. W. WASHBURN, Consolidated Engineering Corporation, Pasadena, California, for the PACIFIC COAST AREA.

CHANGE OF ADDRESS OF BUSINESS MANAGER

MR. J. F. GALLIE, Business Manager of the Society, has changed his address to P. O. Box 1925, Washington, D. C. All communications other than those pertaining to editorial matters should continue to be sent to Mr. Gallie, at his new address.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Roland Leroy Clifton
John A. Gillin, C. G. McBurney, W. B. Hogg
Dallas Robert Davis
J. H. Deming, George D. Mitchell, Jr., Roy L. Lay
Carter Holt Gregory
W. Hafner, H. R. Thornburgh, Harry L. Thomsen
Claude Macy Hathaway
Charles C. Williams, C. G. McBurney, John A. Gillin

Oscar Branche Jackson
F. Goldstone, M. O. Gibson, Claude Wendell Horton
Harold Hunter Jones
T. I. Harkins, R. S. Jackson, Joseph L. Adler
Clarence Henry Leathers
L. F. Athy, Anton H. Erickson, E. J. Handley
Daniel Linehan
M. M. Slotnick, Derry H. Gardner, Joseph Lynch
Phillip Francis Martyn
F. F. Reynolds, J. P. Black, J. P. Schumacher
Mark Howard McKinsey
F. Goldstone, L. K. Mower, Claude Wendell Horton
Linden Jay Richards
Donald Beeth, L. F. Athy, H. R. Prescott
Theodore Rozsa
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Felix Lemuel Yeates

PERSONAL ITEMS

J. ANGELO SMITH, on leave from the Humble Oil and Refining Company, is serving in the Radiation Laboratory of the Massachusetts Institute of Technology, Cambridge, Massachusetts.

CARL L. BRYAN, formerly with the Gulf Research and Development Company, has been commissioned a Lieutenant in the U. S. Naval Reserve. Mail will be forwarded to him from 2405 Isabella Avenue, Houston, Texas.

LEO HORVITZ has organized the HORVITZ RESEARCH LABORATORIES, located at 3217 Milam Street, Houston, Texas.

SHERWIN F. KELLEY reports that he has recently been engaged in geophysical studies by gravitational, electrical, and magnetic methods on zinc deposits in Tennessee, graphite in Pennsylvania, and iron in New Jersey.

LT. CLEVE C. NASH, JR., is stationed with Company C, 27th Signal Training Battalion, Camp Crowder, Missouri.

FLOYD WILLIS, JR., Research Engineer with Geophysical Research Corporation. should be addressed at 2507 N. Boston Place, Tulsa, Oklahoma.

J. P. WOODS, formerly with the Shell Oil Co., Inc., is Research Associate in the Radio Research Laboratory at Harvard University, Cambridge, Massachusetts.

MARK MILSTEIN, consulting geophysicist, has opened an office in New York City at 489 Fifth Avenue. Although he is now stationed in New York, he retains an office at 155 Macpherson Avenue, Toronto, Canada.

W. B. HEROY, President of the Pilgrim Exploration Company, has been named to succeed E. DeGolyer as director of conservation in the Office of the Petroleum Coordinator. He may be reached at the Cosmos Club in Washington, D. C.

R. B. MORAN, JR., is now acting as Research Engineer in the geophysical laboratory of the Superior Oil Company. His address is 3328 Martha Circle, Pasadena California.

N. A. HASKELL is now located at 9 Everett Street, Cambridge, Massachusetts.

W. D. MOUNCE, on leave from the Humble Oil and Refining Company, is serving in the Naval Ordnance Laboratory in Washington, D. C. His residence is 1921 Kalorama Road, N.W.

MAJOR DREXLER DANA may be addressed c/o Mrs. Dana in Newton, Illinois.

A. T. SCHWENNESEN has his office at 2702 Niels Esperson Building, Houston, Texas.

G. W. HOSTETLER has been advanced to the rank of Captain in the Signal Corps. He is now located at 1403 South Main Street, Goshen, Indiana.

O. C. OLSON has completed a six months' contract with the U. S. Engineers as an Associate Engineer and may now be addressed at P. O. Box 349, Brady, Texas.

CAPTAIN G. D. LAMBERT, Battery "F," 63rd CA (AA), is now stationed in Seattle, Washington.

A. E. MCKAY, formerly with the Atlantic Refining Company, is a Lieutenant in the Fighter Command School at Orlando, Florida.

J. E. JETT, Gulf Coast supervisor for the Geotechnical Corporation, may be reached at 408 Sue Street, Houston, Texas.

Copies of a new 36-page booklet, entitled "DU PONT PRODUCTS FOR SEISMIC PROSPECTORS," may be obtained by addressing E. I. du Pont de Nemours and Company, Room 2506-R, Nemours Building, Wilmington, Delaware, while the limited supply lasts. The booklet contains instructive material on the best methods of priming cartridges, loading charges and firing shots, and lists precautions which should be followed in handling, storing and using explosives.

LT. E. L. FETZER should be addressed c/o Mrs. Fetzer, 401 LaSalle Street, Navasota, Texas.

LT. J. P. FARIS, JR., has been transferred from Randolph Field to B. O. Q. Ellington Field, Texas.

R. H. TALLMAN is serving with the International Petroleum Company, Apartado 803, Guayaquil, Ecuador.

NOYES D. SMITH, JR., formerly with the Shell Oil Co., Inc., is serving as physicist in the Naval Ordnance Laboratory, Washington, D. C. His mailing address is 2100 34th Street, S.E., Washington, D. C.

G. C. HOWARD, of the Carter Oil Company, has been transferred to Ferriday, Louisiana, with the postal address Box 548.

JAMES C. TEMPLETON, Managing Director of the Geophysical Prospecting Co., Ltd., of London, England, as returned to England from South America and may again be addressed at 6 Neville Court, Abbey Road, London, N. W. 8, England.

M. L. BENKE has left the Texas Company and is serving as a First Lieutenant in the U. S. Army Signal Corps. He may be addressed at 802 Waverly Avenue, San Antonio, Texas.

LEO J. PETERS, of the Gulf Research and Development Company, has been transferred from Tulsa, Oklahoma, to Pittsburgh, Pennsylvania, with the mailing address Box 2038.

O. F. VAN BEVEREN has left Bahrein Island in the Persian Gulf, where he was serving with the California Arabian Standard Oil Company, and is returning to his home at 4361 Colfax Avenue, North Hollywood, California.

CAPTAIN P. M. HONNELL of the Signal Corps is serving in the Department on Chemistry and Electricity of the United States Military Academy, West Point, New York.

GEORGE B. SOMERS is on travel for the Bureau of Ordnance of the Navy Department. His forwarding address is 1004 Rivermet, Fort Wayne, Indiana.

G. E. WHITE should be addressed at 200 St. Paul's Road N., Hempstead, New York.

L. F. FISCHER has accepted a position as Chief Computer on Party No. 2 of the General Geophysical Company. Mail should be sent him at 833 Fairview Street, Jackson, Mississippi.

MARION A. ARTHUR, on leave from the Humble Oil and Refining Company, is serving in the Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

LOUIS C. PAKISER, JR., recently elected a student member while in attendance at the Colorado School of Mines, has accepted employment as Attached Helper with the Carter Oil Company, P. O. Box 801, Tulsa, Oklahoma.

CLYDE H. WILSON is acting as a Mine Operator, engaged in producing and shipping tungsten ores. His mailing address is Gold Hill, Utah.

HARRY R. IMLE has been advanced to the rank of Captain of Field Artillery and is serving on the Staff and Faculty of the Field Artillery School, Communication Department, Fort Sill, Oklahoma.

J. W. THOMAS, JR., Observer with the Stanolind Oil and Gas Company, should be addressed at Box 652, Mt. Pleasant, Texas.

BULLETIN NO. 15 of "The Experiment Station Soil Mechanics Bulletin" issued by the U. S. Waterways Experiment Station in Vicksburg, Mississippi, contains a German-English vocabulary of soils terms compiled by H. B. Edwards.

MELVIN C. TERRY is on leave from the Humble Oil and Refining Company and is serving in the Naval Ordnance Laboratory in Washington, D. C.

J. W. LOHSE, is serving as Engineer in the Applied Physics Laboratory of Johns Hopkins University, Silver Springs, Maryland.

W. B. WILEY, of the Gulf Research and Development Company, is located at 158 Ridgewood Drive, Metairie, New Orleans, Louisiana.

Former CORPORAL CHARLES C. BATES of Battery A, 2nd F. A. Obsn. Bn., is now an Aviation Cadet, located at 10912½ Wellworth, Village Station, Los Angeles, California.

BILLY E. RICHARDS, of the United Geophysical Company, is located at P. O. Box 946, Perryton, Texas.

DWIGHT E. WARD, formerly of the Carter Oil Company, has accepted foreign employment with the International Petroleum Company, Box 803, Guayaquil, Ecuador.

MAJOR O. T. HALLIDAY, of the Signal Corps, 8th Corps Area, may be addressed at Fort Sam Houston, Texas.

MICHAEL ALLON and R. G. DE GOOD may be addressed c/o Gulf Research and Development Company, Pauls Valley, Oklahoma.

MAJOR EDWARD LIPSON has advised the Society that his address, until further notice, will be 2900 Argyle Drive, Monticello Park, Alexandria, Virginia.

S. A. MARTIN is located at 14 Skahan Road, Belmont, Massachusetts.

MAURICE SKLAR, of the Shell Oil Co., Inc., has been transferred from Groesbeck, Texas, to Wiggins, Mississippi, where his mailing address will be Box 36.

L. L. ANTES, on leave from the Humble Oil and Refining Company, is serving in Engineering Science and Management Defense Training, U. S. Office of Education, University of Texas, Austin, Texas.

CAPTAIN JOHN A. PRANGLIN, Commanding Officer, Co. B., 833 Engr. Bn., may be addressed c/o Judge John L. Pranglin, Pearsall, Texas.

RAYMOND A. PETERSON is acting as Group Supervisor of the Columbia University Division of National Defense Research. His mailing address is 120 Pierce Avenue, East Greenwich, Rhode Island.

FRANCIS A. ROBERTS, of the Carter Oil Company, has been transferred from Hazelhurst, Mississippi, to P. O. Box 622, Norman, Oklahoma.

E. I. HEAD, of the Gulf Research and Development Company, has been transferred from Lubbock to Fort Stockton, Texas, with the mailing address Box 881.

HOWARD ITTEN, of the Stanolind Oil and Gas Company, may be reached at Box 652, Mt. Pleasant, Texas.

E. W. JOHNSON should be addressed c/o Cities Service Oil Company, Geological Department, Pratt, Kansas.

J. M. KILBORN, of the Gulf Research and Development Company, should be addressed General Delivery, Hastings, Nebraska.

J. F. GALLIE, Business Manager of the Society of Exploration Geophysicists, has joined the procurement division of the Naval Ordnance Laboratory in Washington, D. C. His new address is P. O. Box 1925, Washington, D. C.

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